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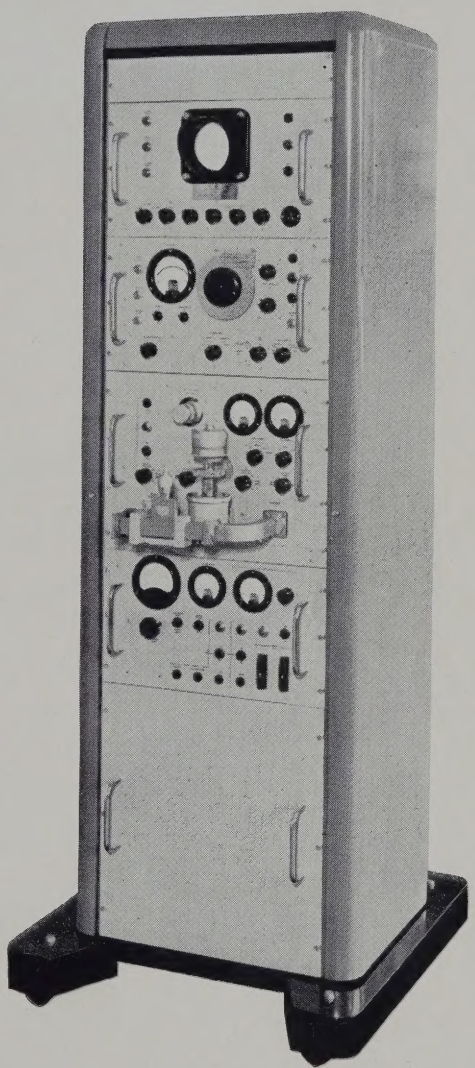
NOISE MEASURING EQUIPMENT TYPE 123



Requirements for exceptionally low noise performance in microwave oscillators and allied devices have led to the development of a new type of R.F. spectrum analyser capable of accurately measuring A.M. and F.M. noise spectrum at frequencies close to carrier.

This handbook includes a description of the theory upon which the operation of the instrument depends and serves as an introduction to the technique. A series of detailed operational and instructional handbooks are supplied to users of the equipment which can be supplied for a number of C and X-band frequency ranges. Equipment for other bands may be supplied to order.

The basis of the technique employed is a novel R.F. frequency discriminator combined with a double channel receiver. This system was originally developed by the Royal Radar Establishment (British Patent Application No. 28284, Marsh & Clare*) and is now available commercially by courtesy of the Ministry of Supply.

The illustration shows an X-band version of the Type 123 instrument, but equipments for other frequency bands can be supplied.

* Also protected in Canada and U.S.A. etc.

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JAMES SCOTT & CO. (ELECTRICAL ENGINEERS) LIMITED.

Manufacturing & Electronics Division.

NOISE MEASURING EQUIPMENT TYPE 123.

Technical Note 123/01.

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NOISE MEASURING EQUIPMENT TYPE 123.

by

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SUMMARY.

The equipment described permits the measurement of spurious modulations arising in microwave CW oscillators and allied devices at very large signal-to-noise ratios at frequencies close to the carrier.

The instrument may be used to measure amplitude modulation of the carrier, the result being expressed as a signal-to-noise ratio* or alternatively, frequency modulation of the carrier in which case the result is expressed in terms of the RMS frequency deviation produced by the noise in a specified narrow frequency band.

Equipment suitable for operation in variousfrequency ranges from 5 to 11 Kmcs. have been developed with several alternative resolutions. For simplicity data is given in this article relative to the performance of the standard X-band equipment but comparable results can be obtained at other frequencies.

For FM measurements the sensitivity is high. For example a deviation of .01 c/s is a 70 c/s bandwidth has been measured at a frequency within several Kc/s of carrier. Amplitude modulation, signal-to-noise ratios of the order of 135 db can be measured. The design of the equipment, particularly the RF section, has been carefully directed to reducing the inherent noise to the lowest practicable level.

1.0 INTRODUCTION.

Progressive developments in the engineering and application of microwave systems call for increasingly precise measuring apparatus and present day performance specifications for microwave oscillators and allied devices prove no exception to this general rule.

* Meaning the ratio of carrier power to the sideband power.

For example, the purity of the CW output from an oscillator will be limited by noise originating in the tube itself and random variations in the operating levels of power supplies, resulting in spurious AM and FM of the tube output. The spurious modulations are apparent as noise effects which impose limitations either directly or indirectly on the sensitivity and efficiency of a given system. In particular, in doppler navigation and similar systems, the signal spectrum may lie in the region close to the carrier frequency where the noise is likely to be most significant. In determining the limiting sensitivity of a system with a narrow signal spectrum - possibly in tens or hundreds of kilocycles - it is generally quite useless to measure average noise power over a wide band of frequencies because the noise spectrum may be a rapidly varying function of frequency. Apart from this, there may be present unwanted components just as objectionable as random noise but arising from other causes. For example, signal breakthrough from various components of a system, including harmonics of the power supply frequency. It follows that a resolution of a few tens of cycles may be necessary.

The main requirements for a spectrum analyser for the particular purpose described are, therefore, as follows:-

1. The ability to distinguish between frequency and amplitude modulated noise and to present these spectra independently and with adequate isolation.

2. A narrow-band filter or "window" which may be located, for the purpose of making noise power measurements, at an accurately known frequency separation from the carrier

3. A high order of sensitivity.

These criteria have been met in the system which will now be described. In addition, tuning is not too critical and the sensitivity of the system can be readily checked, from time to time.

An R.F. input circuit and receiver is used in conjunction with a narrow band spectrum analyser with alternative panoramic or manual display facilities. The RF unit comprises an input waveguide circuit followed by a two-channel superheterodyne receiver, the separate IF amplifiers being supplied from balanced mixers in order to materially reduce the effects of local oscillator noise.

In one arrangement of the connecting circuits the receiver functions as a frequency discriminator, providing linear conversion of an FM carrier signal to an amplitude modulated IF signal which is fed to a linear second detector. In this mode of use a high rejection of spurious carrier AM is achieved.

For the measurement of spurious carrier AM, only one IF channel is used in a straightforward superhetrodyne conversion from RF to IF, followed by linear second detection.

The output from the second detector will be a video signal having an amplitude time characteristic corresponding to the amplitude modulated envelope of the RF carrier on the one hand, or to the frequency time deviations of the carrier on the other. In order to determine completely the nature of the spurious modulations, it is necessary to examine the spectrum of the video signal both visually and quantitatively and this can be done with the aid of the spectrum analyser, which forms an integral part of the complete instrument which is known as a Noise Measuring Equipment. A visual examination of the spectrum is generally necessary in order to enable the presence of lines corresponding to fixed frequency steady-state components to be identified and thus distinguished from random noise components.

A number of systems have been designed for X and C-band frequency ranges, including several alternative arrangements for the video spectrum analyser. The performance data quoted in this article has been determined by measurements on an X-band equipment as shown in the accompanying illustration.

This equipment incorporates an RF milled block assembly, manufactured by Ferranti Ltd., comprising the whole of the microwave bridge and mixer circuits. In addition to the saving in space that results, the use of the milled block technique ensures the highest possible stavility in the microwave circuit and, in particular, reduces the possibility of the limiting sensitivity being strongly influenced by microphony in the waveguide circuit. Unfortunately, it is not always possible to make use of this technique as the extra cost and development time may prove prohibitive. The C-band equipments use standard waveguide components, but because of the generally larger dimensions, the dangers from microphony are much less.

2.0 RF SYSTEM

2.1 General Principles

Fig. 1 shows a block diagram of the system. The reference channel IF amplifier is fed from the source and the input to the signal channel is obtained from a frequency discriminator in the form of an RF bridge.

When the bridge is balanced, the output versus frequency response curve will be of the form shown in Fig. 2 where the null occurs when the bridge cavity is tuned to the signal frequency. If a sinusoidal variation in source frequency occurs, the bridge output amplitude will vary in the manner shown in the diagram. It will be noted that a sign detector is required to enable the sense of the frequency deviation to be determined. It is, therefore, necessary to provide a second signal channel to derive a reference signal for the sign detector.

The sign detector, conventionally, comprises a hybrid transformer giving sum and difference outputs which are subsequently applied to linear detectors. Thus, the output from the second detector is an amplitude varying voltage which follows the sense of the initial frequency deviation and FM spectra can be plotted with a spectrum analyser have a sufficiently high order of resolution.

The above description refers to ideal conditions and in practice the situation is complicated by imperfections in the performance of some of the components without, however, changing the basic method implied.

By removing the hybrid coupling at the input to the two channels, either of them may be used (with alternative second detectors), for comparing AM spectra or mean power. It is also possible to use the sign detector with separate channel inputs in order to compare FM or PM. relationships between RF signals from different points on a transmission network.

A circuit diagram of a typical X-band system is shown in Fig. 3.

Output power from the tube on test is brought to the instrument and coupled via a 45 db variable attenuator to the waveguide assembly.

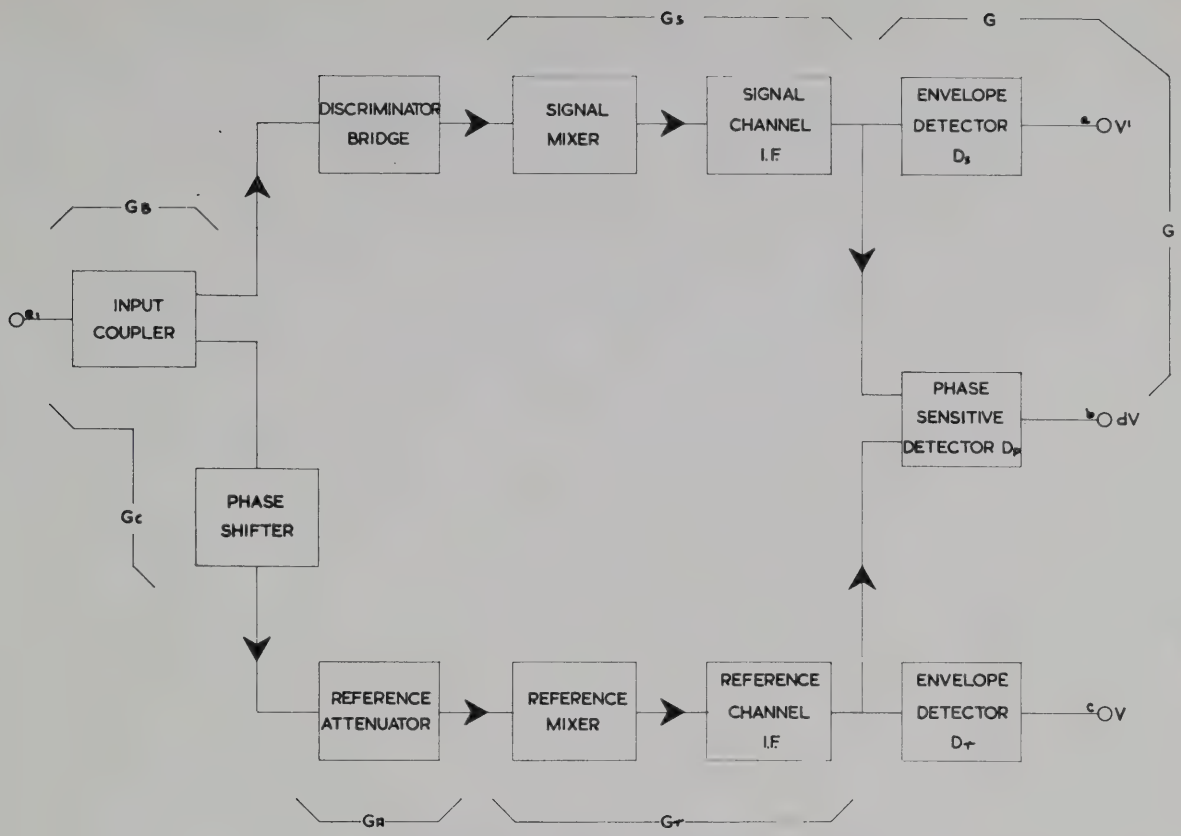

Fig. 1. Theoretical Schematic Diagram of Receiver

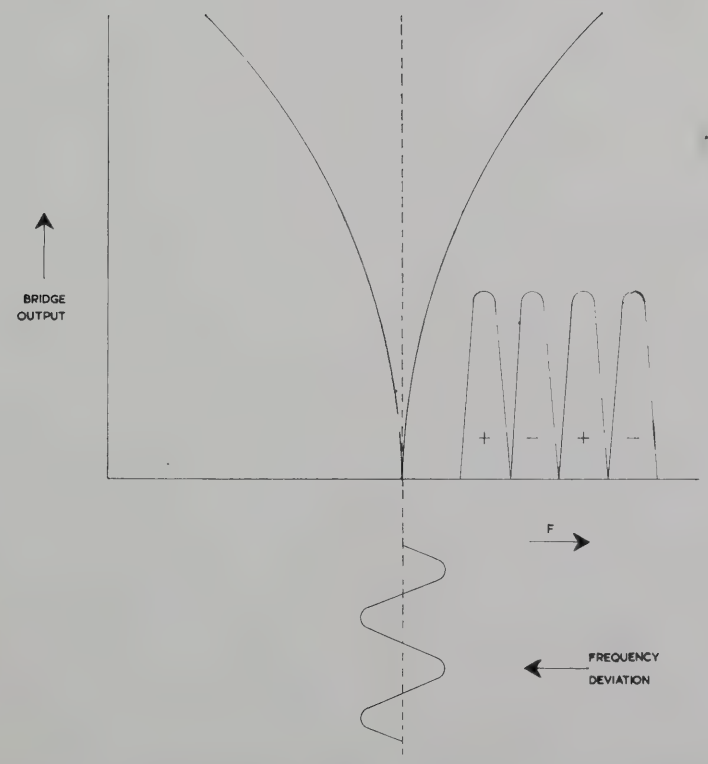

Fig. 2. Characteristic Response of Frequency Discriminator

The reference channel is supplied via a 10 db coupler, phase shifter and attenuator and the output from the bridge hybrid goes to the signal channel. The input power to the bridge is split by a hybrid junction to arms terminated by the tunable cavity in one arm and by a variable 20 db attenuator and short circuit in the other.

Balanced mixers are used in both channels to improve the noise factors of the receivers by minimising the effects of local oscillator noise at the intermediate (first conversion) frequency.

The cavity, which for the X-band systems has an unloaded Q of greater than 20,000, is matched to the waveguide so that it presents a VSWR of better than 0.9 over a frequency range of approximately $\pm$10% relative to the design centre frequency. The variable attenuator and adjustable short circuit together present a variable impedance to the hybrid. This gives smooth control of the impedance on the balancing arm and enables a good bridge balance to be obtained for imperfect matching on the cavity arm.

Unfortunately, the match of the cavity is not the only limitation on bandwidth. The available sensitivity is determined primarily by the magnitude of the residual carrier power in the output from the bridge circuit and by the inherent noise factor of the receivers. It follows, that the directivity and balance of the mixer hybrids must be very good in order to obtain optimum sensitivity and, in practice, a balance of better than 0.1 db and directivity of at least 23 db is specified and leads to a practical bandwidth of about $\pm$4%. It will be appreciated that this bandwidth limitation only applies to the case where the ultimate in performance is required and measurements can be made over a somewhat wider bandwidth if a sacrifice in sensitivity is tolerable.

It is convenient to mention here that the response of the sign detector will be unaffected by variations in reference signal amplitude only if there is good phase tracking between the two amplifiers over the IF bandwidth. The RF phase shifter is used to control the phase relationship, and phase alignment over the IF band is ensured by extremely careful, symmetrical construction and alignment of the IF's and the sign detector hybrid.

It is the accuracy of phase alignment between the two channels together with the magnitude of the FM/AM conversion factor which determine the extent to which discrimination against residual signal AM occurs when FM measurements are made.

2.2 FM to AM Conversion Sensitivity.

The theory of FM measurement, including FM to AM conversion sensitivity and limiting sensitivity can be found quite simply from first principles. It is convenient to use equivalent lumped circuit parameter concepts in deriving the characteristic formulae for the microwave discriminator. The result is a simple relationship between frequency deviation and voltage levels which are measured at the output from the R.F. unit.

It can be shown that the measurement system is self-checking in that, after an initial calibration to determine the values of certain constants, subsequent adjustment to set up the required sensitivity, can be made using only a simple low-powered CW test source which need not be modulated. This is an important point since it is not easy to set up sources with accurately known degrees of modulation at the levels with which we are concerned in this work. Quite apart from the time-saving aspect, there is a high degree of certainty about the accuracy with which measurements will be made.

Consider the equivalent circuit of the RF receiver in Fig.1.

The parameters of interest are:-

G_s .. the gain of the signal channel from the crystal mixer to the input of the envelope detector D_s.

G .. the gain from the input of D_s to the output of the phase sensitive detector D_p.

G_r .. the gain of the reference channel from the crystal mixer to the input of the envelope detector D_r.

G_B .. the 'gain' across the input coupler in the series branch.

G_C .. the 'gain' across the input coupler in the transfer branch.

G_A .. the 'gain' across the reference attenuator and phase shifter.

e_i .. the RMS RF voltage at the input to the receiver.

e_i^1 .. the RMS RF voltage at the input to the bridge.

e_o .. the RMS RF voltage at the input to the signal channel mixer.

e_r .. the RMS RF voltage at the input to the reference channel mixer.

dV .. the change in voltage measured at the output from the phase sensitive detector D_p, for a change df in RF frequency.

V .. the measured output from the reference envelope detector.

f_o .. carrier frequency

d_f .. a small deviation relative to the carrier frequency f_o.

f .. a modulation frequency.

Q_c .. the unloaded Q of the FM discriminator cavity.

n .. the ratio of the input e_i to the reference channel signal level e_r.

The discriminator is essentially a balanced microwave bridge and is sketched schematically in Fig.4. The bridge arms comprise matched input and output waveguide branches a and d, arm b which is coupled to a high Q cavity and a fourth arm, c, which comprises a variable 20 db attenuator and a tunable short circuit.

The components in the "balance" arm, c, may be adjusted so as to present a variable impedance to the hybrid in order to compensate for any small mismatch which may exist between the cavity and arm b at resonance and so maintain an equal division of power between b and c and also ensure that reflections arising in these junctions as a result of the mismatch are self-cancelling in the output arm d.

The cavity is tuned to the carrier frequency f_o and the balancing components are adjusted for a minimum output e_o. In order to find out what happens when the carrier frequency is

altered by a small amount, it is convenient to consider a lumped parameter equivalent circuit for the cavity arm.

At frequencies close to resonance, a cavity can be represented by a simple LC circuit (see Fig.5) whose impedance for high Q is quite accurately represented by the equation:-

$$Z = Z_o\left(1 - 2j\,\frac{df}{f_o} \cdot Q_c\right) \qquad \ldots\ldots\ldots (1)$$

where $Z_o = \frac{L}{RC}$,

the impedance at resonance, which is of course purely resistive in the case of the simple, approximate model chosen.

Let Z_r be the characteristic impedance of the guide, then for a match at resonance $Z_r = Z_o/K^2$ and, in general, the impedance of the cavity is normalised to the guide impedance. The cavity impedance as seen looking into the guide branch b is, therefore,

$$Z_b = Z_r\left(1 - 2j\,\frac{df}{f_o} \cdot Q_c\right) \qquad \ldots\ldots\ldots (2)$$

If e_b is the magnitude of the incoming signal voltage, and e_{br} the reflected voltage arising from the small mismatch represented by equation (2), then:

$$\left|\frac{e_{br}}{e_b}\right| = \left|\frac{Z_r - Z_b}{Z_r + Z_b}\right| = \frac{d_f}{f_o} \cdot Q_c \qquad \ldots\ldots\ldots (3)$$

Now, from the properties of a directional coupler or magic tee

$$e_b = e_i{}^1/2^{\frac{1}{2}} = e_i G_B/2^{\frac{1}{2}} \text{ and } e_o = e_{br}/2^{\frac{1}{2}}$$

$$\therefore \quad \frac{2e_o}{G_B e_1} = \frac{df}{f_o} \cdot Q_c \qquad \ldots\ldots\ldots (4)$$

Also, by definition $n = e_i/e_r$

$$\therefore \quad \frac{d_f}{f_o} = \frac{2}{G_B Q_c} \cdot \frac{e_o}{e_i} = \frac{2}{G_B Q_c} \cdot \frac{e_o}{n e_r} \qquad \ldots (5)$$

Now, $e_o = dV/G.G_s$ and $e_r = V/G_r$ ..... (6)

$$\therefore \quad \frac{d_f}{f_o} = \frac{2}{nQ_c} \cdot \frac{dV}{G.G_s.G_B} \cdot \frac{G_r}{V}$$

$$\therefore \quad d_f = \frac{dV}{V} \cdot \frac{2f_o}{\frac{G.G_s.G_B.n.Q_c}{G_r}} \quad \text{.....} \quad (7)$$

It is shown later that the term in the brackets in equation (7) can be accurately determined and that once found for a particular frequency, f_o, the system can be readily adjusted to maintain constant sensitivity thereafter.

This equation is derived from steady-state considerations, but is equally applicable where d_f and consequently dV are functions of time. The varying output from the phase sensitive detector is examined by the video spectrum analyser which measures the RMS magnitude of the components of (dV) which lie in a predetermined narrow band of frequencies. On the other hand, the level V measured at the output from the reference channel represents the peak carrier amplitude and it is the ratio between these two quantities which is defined as the "signal-to-noise ratio".

Equation (7) may be written:

$$\frac{dV}{V} = \frac{d_f}{f_o} \left(G.\frac{G_s}{G_r}.nG_BQ_L\right) \quad \text{.....} \quad (8)$$

where Q_L is the loaded Q of the matched cavity and the conversion sensitivity is proportional to the magnitude of the term in the bracket. The factor $G.G_s/Gr$ approximates unity for maximum receiver sensitivity and G_B is a small loss factor which does not exceed 1 db. It follows that only the product $n\ Q_L$ is significant in determining sensitivity.

The maximum possible value of Q_L is generally determined, not so much by practical engineering limitations as by the required range of linear FM to AM conversion. If f is the maximum modulation frequency, then the required bandwidth for linear operation of the discrminator is 2f so long as the ratio df/f is less than 0.4. Also, the effects of imperfect bridge balance and relatively slow frequency drift in the oscillator under test during the course of a measurement must be considered and the linear range increased accordingly. For example, a modulation range of 120 Kc/s

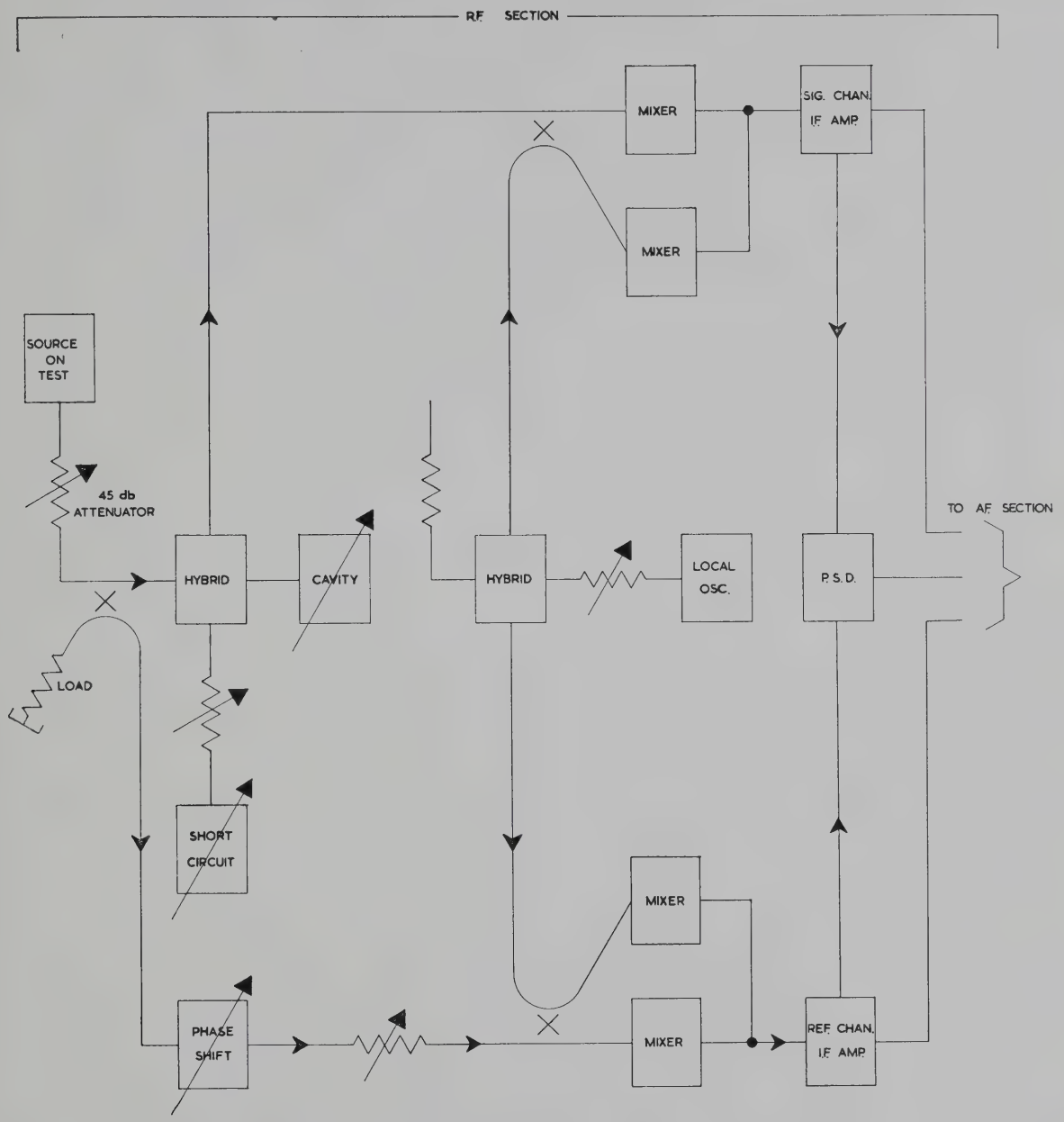

Fig. 3. Schematic Diagram of Microwave Receiver

requires a minimum 3 db bandwidth of about 600 Kc/s in practice, and the maximum practicable cavity Q is limited to rather less than 20,000.

Having determined the permissible magnitude of Q_L in a particular case, it only remains to consider the remaining factor 'n'. This, it will be remembered, is the ratio of the test oscillator voltage at the input of the system to the voltage which would be measured at the input to the reference channel mixer. The maximum signal power level at this point, as determined by the power handling capacity of crystals, is about 400 uw, so the first limitation is the power available from the test oscillator and the next arises from the operation of the discriminator in the signal channel. The residual signal power level at the input to the signal channel mixers has to be about 10 dbs down on the signal power at the reference channel mixer in order to ensure linear operation of the sign detector at the output from the IF's; this level will be about 40 uw. It follows, therefore, that the maximum permissible value of the ratio 'n' will be determined entirely by the degree of carrier cancellation obtained in the discriminator, providing adequate power is available from the source.

The effective carrier cancellation obtainable will depend not only on the degree of balance provided by manually tuning the bridge, but also on the stability of the frequency of the test source and, in practice, it has been found that maximum values of 'n' varying from 20 to 40 db are practicable, depending on the quality of the tube under test.

Referring again to equation (8), the voltage V at the output from the reference envelope detector is nominally 4 volts. Assuming an input power of 400 mW and a Q_L equal to 15,000 and an 'n' factor equivalent to 30 db, the frequency deviation sensitivity at the output of the phase sensitive detector may be calculated to be approximately 270 microvolts/c/s deviation. This sensitivity may be adjusted over fairly wide limits by increasing or decreasing the input power to the bridge.

2.3 Limiting Sensitivity

The limit of sensitivity to be expected from the equipment may be deduced as follows:-

The available thermal noise power in a one cycle bandwidth at room temperature is -204 dbw and a typical noise figure for each receiver is 13 db. Therefore, for a 100 c/s noise bandwidth

the available noise power at the mixers is -(204-20-13) = -171 dbw .. (9)

Now, the signal input power level at the mixer, which is required to give 4 volts output at the reference envelope detector, is approximately 400 microwatts, i.e. -33 dbw ..... (10), so that the ratio of signal input to system noise is 137 dbs, (i.e. equation (9) - equation (10)), and this figure represents the theoretical limiting sensitivity of the equipment under the conditions specified.

Measurements of AM modulations corresponding to signal-to-noise ratios approaching 137 dbs may, therefore, be made on the reference channel or, indeed, on the signal channel if the bridge is detuned. This sensitivity is not exceptional but adequate, and it should be remembered that the primary purpose of the system is the measurement of FM.

The limiting FM sensitivity is obtained when the measured RMS noise voltage level at the output of the sign detector is -137dbs relative to 4 volts. Since a typical figure for the frequency deviation sensitivity is 270 microvolts/c/s deviation, it follows that the system is limiting for a deviation of 0.003 c/s approximately.

The results quoted are optimistic, since the preceding discussions are based on several approximations and assumptions. In particular, the effects of combined FM and AM have not been considered. In this connection, it may be observed that the use of the sign detector enables some 30 dbs of rejection of residual AM on the reference channel to be obtained. Also, while in the bridge circuit, FM is converted to AM at the output (consider the relation of equation (3) operating on a pair of equally spaced sidebands), conversely AM is converted to FM and the sign detector discriminates against (converted) AM when the reference phase is correctly adjusted.

In practice, it has been found possible to measure signal-to-noise ratios of the order of 133-135 dbs in both AM and FM on X-band sources. The corresponding limiting sensitivity in terms of frequency is approximately 0.01 c/s deviation in a 100 c/s band for FM and this sensitivity can be achieved in the presence of significant, but not over-riding, AM noise.

2.4 Calibration

In order to use the equipment, it is necessary to have calibration data for the cavity and reference attenuator and to know the transmission loss/frequency characteristics corresponding to the parameters G_A and G_B. These can readily be determined by normal laboratory measurement techniques. With this data, the following

system checks can be rapidly executed, when necessary. All that is needed is an external test source capable of providing about 500 mw of RF power, and 'quiet' with respect to AM noise and stable in frequency.

2.4.1 Relative gain factor (G_s/G_r)

With the cavity detuned, the attenuation of signal voltage over the discriminator network will be 6 dbs, and the loss in the series branch of the input coupler, corresponding to factor G_B in equation (8), may be assumed to be approximately $\frac{1}{2}$ db. Assuming the transfer branch attenuation of the input coupler is 10 db and the phase shifter introduces negligible loss, the difference in voltage levels e_o and e_r (Fig.1) will correspond to 10-6.5 = 3.5 db.

The signal levels V^1 and V at the signal and reference envelope detectors for equal IF and mixer gains should, therefore, be in the ratio of 1.5 : 1, and any significant departure from this figure indicates the gain difference between the two channels and the relative gain ratio G_s/G_r may be calculated.

2.4.2 Gain from signal envelope detector to sign detector output (G)

The output voltage levels from the signal envelope detector and from the phase sensitive detector are monitored for a suitable level of input voltage and with the reference phase shifter adjusted to give maximum output. The ratio between these outputs then gives the magnitude of G.

Referring again to equation (8), it may be noted that the parameters Q_L, G_B and n are all determined, or determinable, from the initial calibration data and it is only necessary to carry out the tests 2.4.1 and 2.4.2 above in order to check the sensitivity equation.

The limiting sensitivity may be determined at the same time and with the same test source, providing the noise from the source is at a sufficiently low level.

Since, in practice, the equipment will normally be used for measurements on high quality oscillators, the oscillator under test will usually have an adequate performance and, in such a case, the system may be described as self-checking in that no external sources or test gears are required.

3.0 VIDEO SPECTRUM ANALYSER

The video spectrum analyser used with the NME is a self-contained instrument. A schematic diagram of this unit is shown in Fig.6 with data appropriate to a 90 Kc/s modulation range.

The three available outputs from the RF receiver are taken to a selector switch at the input to the video spectrum analyser. Whether or not the investigation interest lies in FM or AM spectra, the outputs from the demodulators or sign detectors are video signals and their RMS values may be determined immediately by means of monitoring detector current meters.

In many cases, however, it will be necessary to examine the spectra of the converted signals and this function is achieved by the spectrum analyser. A schematic diagram of this unit is shown in Fig.4.

The video signal is first amplified and then fed to a wide-band mixer, the reference carrier into the mixer being derived from a manually tuned calibrated oscillator with a tuning range from 101 to 190 Kc/s, but with the dial calibrated in terms of the difference frequency, i.e. 1 to 90 Kc/s. Sum and difference frequency components are generated in the mixer and appear as output signals which are coupled into a frequency selective amplifier centred on 100 Kc/s. Thus, only difference signals having frequency components within the pass-band of the tuned amplifier (which is arranged for sharp cut-off beyond its range) are transmitted through to the final stages and measuring circuits of the equipment. For quantitative work, the output power in either a 70 c/s or a 1 Kc/s band of frequencies is determined by means of a thermocouple microammeter and the manual oscillator can be tuned through its range. Noise power measurements can then be made as frequently as desired. In order to permit qualitative visual examination of the spectrum, provision is made to switch out the manually tracked local oscillator covering the required difference frequencies in two ranges, 1-7 Kc/s and 1-90 Kc/s. The local oscillator sweep voltage is used to derive the time base of an oscilloscope employed for viewing the spectrum.

On the 1-7 Kc/s range, the 70 c/s band-pass amplifier is used, but the bandwidth is increased to 1 Kc/s for automatic sweep on the 1-90 Kc/s range in order to produce an easily read spectrum curve.

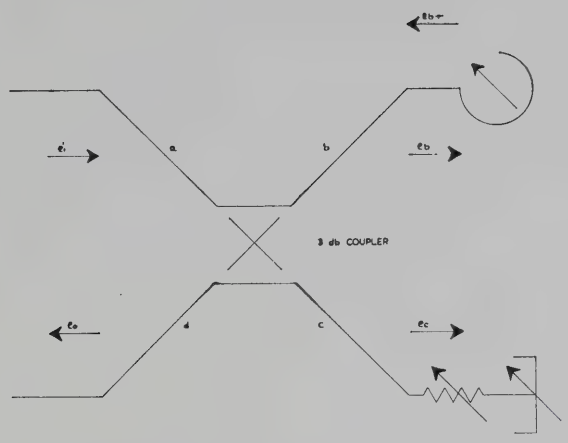

Fig. 4. Frequency Discriminator — Microwave Bridge

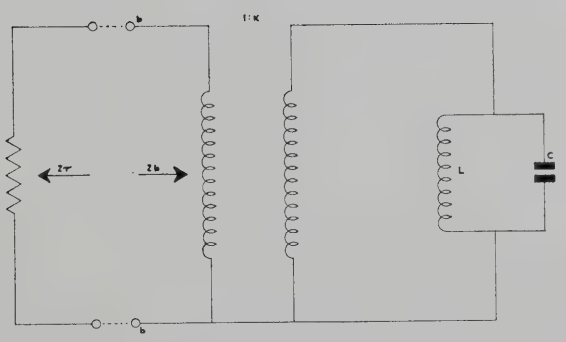

Fig. 5. Equivalent Circuit of Cavity branch

Fig. 4. Frequency Discriminator — Microwave Bridge

Fig. 5. Equivalent Circuit of Cavity branch

The sweep rate is necessarily rather low in order to avoid distortion and loss of signal through the narrow-band amplifier and it is, therefore, necessary to incorporate a medium or long persistence C.R.T. in the display unit.

Calibration of the time base is effected by a marker trace signal derived from the manual oscillator and coupled into the noise amplifier before the mixer circuit. A crystal controlled local oscillator is used as a reference in the marker frequency mixer. This method of deriving a marker signal has the particular advantage that once any line on the display has been 'pointed' by a marker blip, very little further adjustment of oscillator frequency is necessary to peak the meter reading on switching to "manual", since the same oscillator output is employed.

4.0 SUMMARY OF PERFORMANCE.

The complete system of measurement conveniently divides into the RF discriminator-receiver and spectrum analyser units. The following paragraphs give the main performance details for an X-band equipment.

4.1 RF Discriminator-Receiver.

Nominal bridge input power:

400 mw.

Maximum input power without external attenuation:

3.0 watts.

Discriminator sensitivity:

appro. 250 uV/c/s (Measured at sign detector) for nominal input power.

Discrimination against residual AM:

Better than 10 db.

IF bandwidth:

2 Mc/s (to 1 db points)

Nominal output level at reference detector:

4.0 volts.

4.2 Spectrum Analyser.

Frequency range:

The equipment measures the power level in a selected bandwidth centred at a variable frequency in the range 0.5-95 Kc/s

Bandwidth:

Two alternative bandwidths are available, namely 70 c/s and 1 Kc/s. Both bands may be used for accurate noise power measurements by a thermocouple milliameter or, alternatively, for the panoramic display.

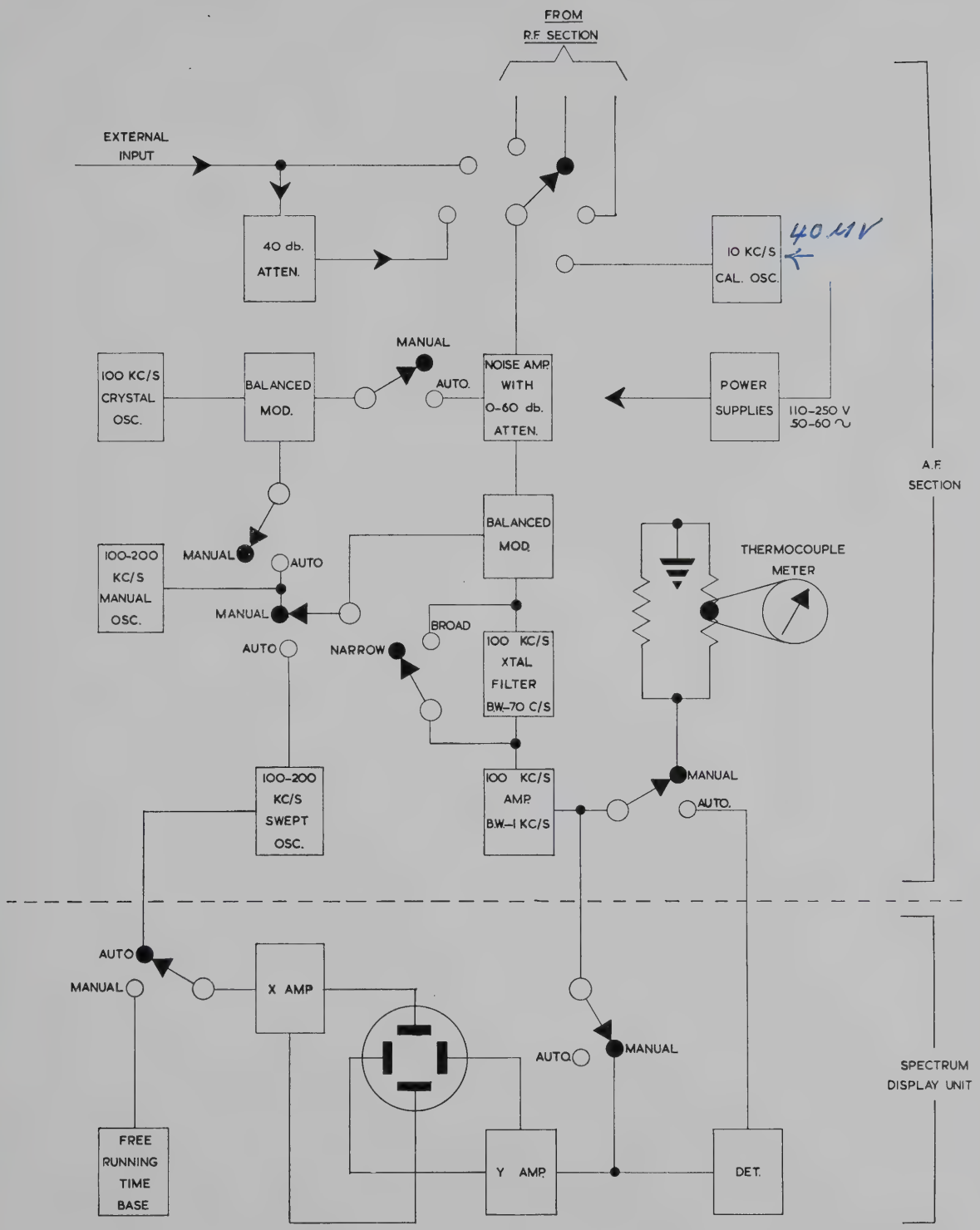

Fig. 6. Schematic Diagram of Video Spectrum Analyser Type 190

Presentations:

(a) Automatic:

An oscilloscope which forms part of the equipment is used in conjunction with the spectrum analyser circuits to produce

(b) Manual:

Accurate power measurements are made by using a manually tracked heterodyne oscillator calibrated in terms of the video signal frequency. Calibrated attenuators are employed to adjust the output power to a constant reading on a thermocouple milliameter. The attenuators read signal power level with reference to a 40 microvolt calibrating signal at 10 Kc/s.

An auxiliary function of the display tube is to monitor the output signal from the selective amplifier in manual operation.

(c) Frequency marker:

A merker system gives ease of alignment of the manual frequency control with any section of the oscilloscope display, and permits rapid calibration of it.

Sensitivity and accuracy:

Input signal components in the range from 0.1 volt to 1 microvolt r.m.s. in a 70 c/s band (a range of 100 db) can be measured with an accuracy of ± 2 db at frequencies from 500 c/s to 90 Kc/s. Measurements down to 200 c/s and up to 95 Kc/s can be made by correcting for reduced amplifier sensitivity.

The inherent noise level of the equipment corresponds to approximately 0.20 microvolt in a 70 c/s band referred to the input terminals at 5 kilhom input impedance.

Oscilloscope:

The display unit incorporates a 4 inch C.R.T. with the usual adjustable controls. The front panel is provided with a viewing hood and camera mount. Both X and Y plates are driven symmetrically by simple paraphase amplifiers. The 'time base' voltage is derived from the generator controlling the sweep

oscillator, or alternatively, from a built-in, free-running, sawtooth generator, which is a useful aid in distinguishing random noise from periodic signal components.

It is important to note that the spectrum analyser is a very useful analytical instrument in its own right. It may be used for noise and line analysis at audio ranging to supersonic frequencies for such typical applications as the performance of tube and transistor circuit configurations, and with suitable transducers for vibration analysis within its frequency range. The magnitude of small harmonic signal comppnents of noise of considerably greater RMS amplitude can be detected at RF by employing a suitable super-heterodyne receiver.

The spectrum analyser with display unit is also marketed as a self-contained instrument under the type reference 190. A detailed description of this instrument is given in a companion publication, Technical Report No. 190/01.

3.3 Sensitivity of the complete system.

Effective FM sensitivity:

Subject to the practical limitations on sensitivity imposed by the need to satisfy equation (8), particularly with regard to test source stability, the following performance is typical:

Limits of FM Sensitivity:

If the test oscillator has a sufficiehtly good performance to enable a bridge balance of 50 db to be maintained, deviations down to 0.01 c/s in a 70 c/s bandwidth can be measured in the absence of over-riding AM noise. At the other extreme, the FM limit is 300 c/s deviation.

AM Sensitivity:

Signal-to-noise ratios of the order of 135 db can be measured.

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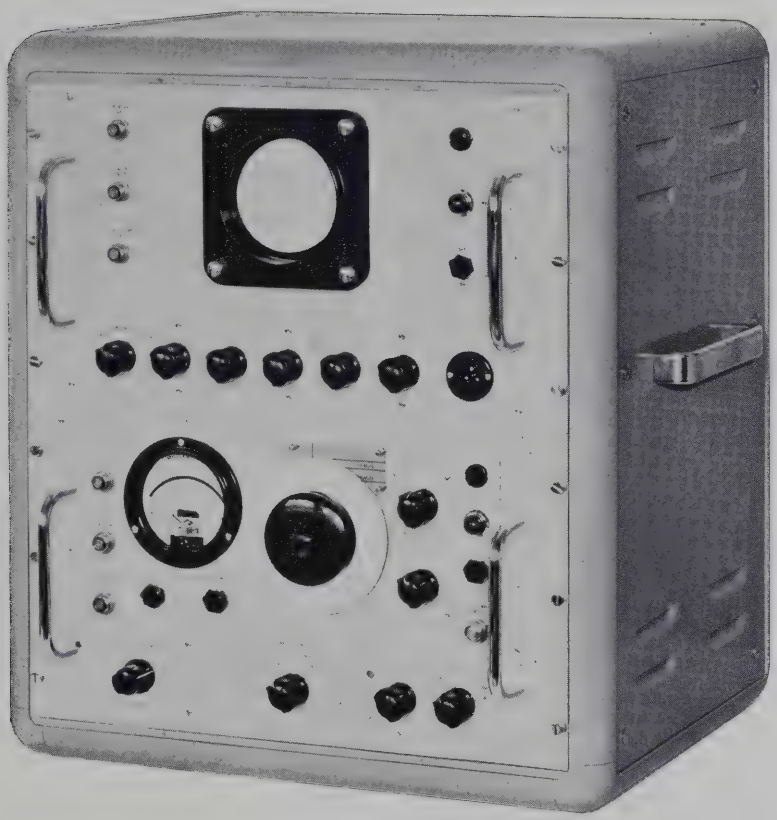
ELECTRONICS

SPECTRUM ANALYSER TYPE 190



Spectrum Analyser Type 190 is an instrument of exceptional range and sensitivity for audio to supersonic frequencies. Among many oustanding features, the analyser has a dynamic range of 50 dbs, a calibrated range of 100 db (down to levels of 1 microvolt, or less) and a self-contained power-indicating meter facility which enables a quantitative measurement of the signal power present in a fixed narrow frequency band, at any desired mean frequency, to be determined. A visual panoramic display is also provided.

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SPECTRUM ANALYSER TYPE 190

1.0 INTRODUCTION

1.1

A spectrum (or wave) analyser is basically a four-terminal selective or band-pass filter whose centre or mean frequency f_0 can be varied in a known manner to any value between two desired frequency limits. Coupled to the output terminals of the network is an indicator, which provides a measure of the output from the filter (see Fig. 1 (a)). Such an instrument can be employed to obtain the Fourier series corresponding to a complex harmonic waveform or, alternatively, a noise spectra, or a combination of both types of signal. The single criterion, which must be satisfied to enable measurements to be made, is that the RMS value of the signal components within the pass band of the analyser must remain constant when integrated over a sufficiently long period of time. This criterion is obviously satisfied by the nature of harmonic waveforms, however complex, and also by any signal which has the characteristics of electrical noise arising from molecular phenomena. It is not satisfied if the signal contains isolated, discontinuous, noise or harmonic components of short duration and random amplitude/frequency distribution.

Fig. 1 (A) Basic elements of a Spectrum (or wave Analyser.

1.2

Any attempt to plot a spectrum by means of the simple system outlined above tends to be a time-wasting, laborious process, involving separate amplitude and frequency measurements at every point on the spectrum at which information is required. Practical analysers are designed to present this information rapidly and in an easily assimilated form.

The effective centre frequency f_0 is frequently changed or " swept " automatically between the required limits, while the X-plate potentials of an oscilloscope are varied in synchronism. At the same time, the filter output signal is amplified and applied to the Y-plates of the tube, so that an amplitude-frequency graph is plotted on the face of the C.R. tube, as indicated in the schematic diagram, Fig. 1 (b).

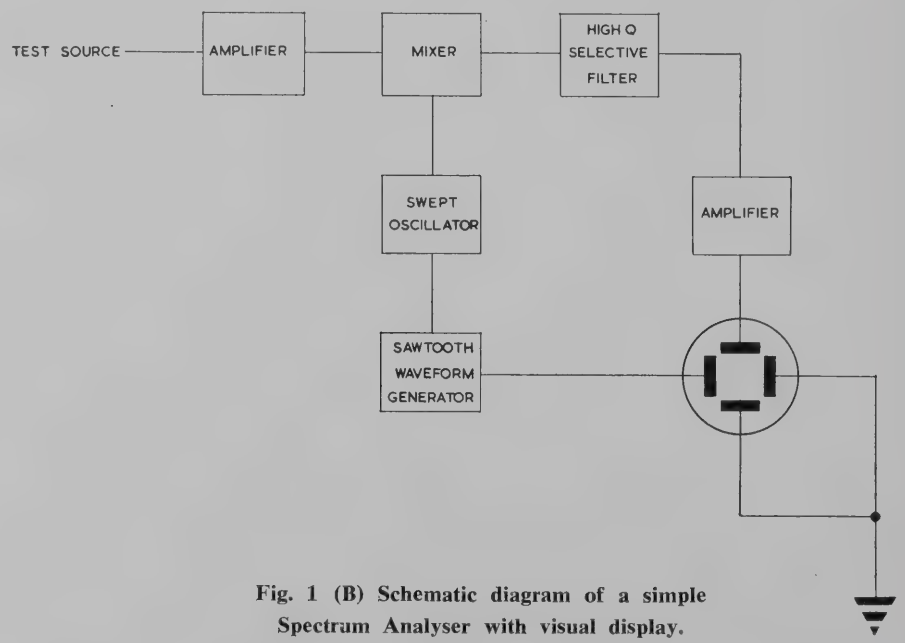


Fig. 1 (B) Schematic diagram of a simple Spectrum Analyser with visual display.

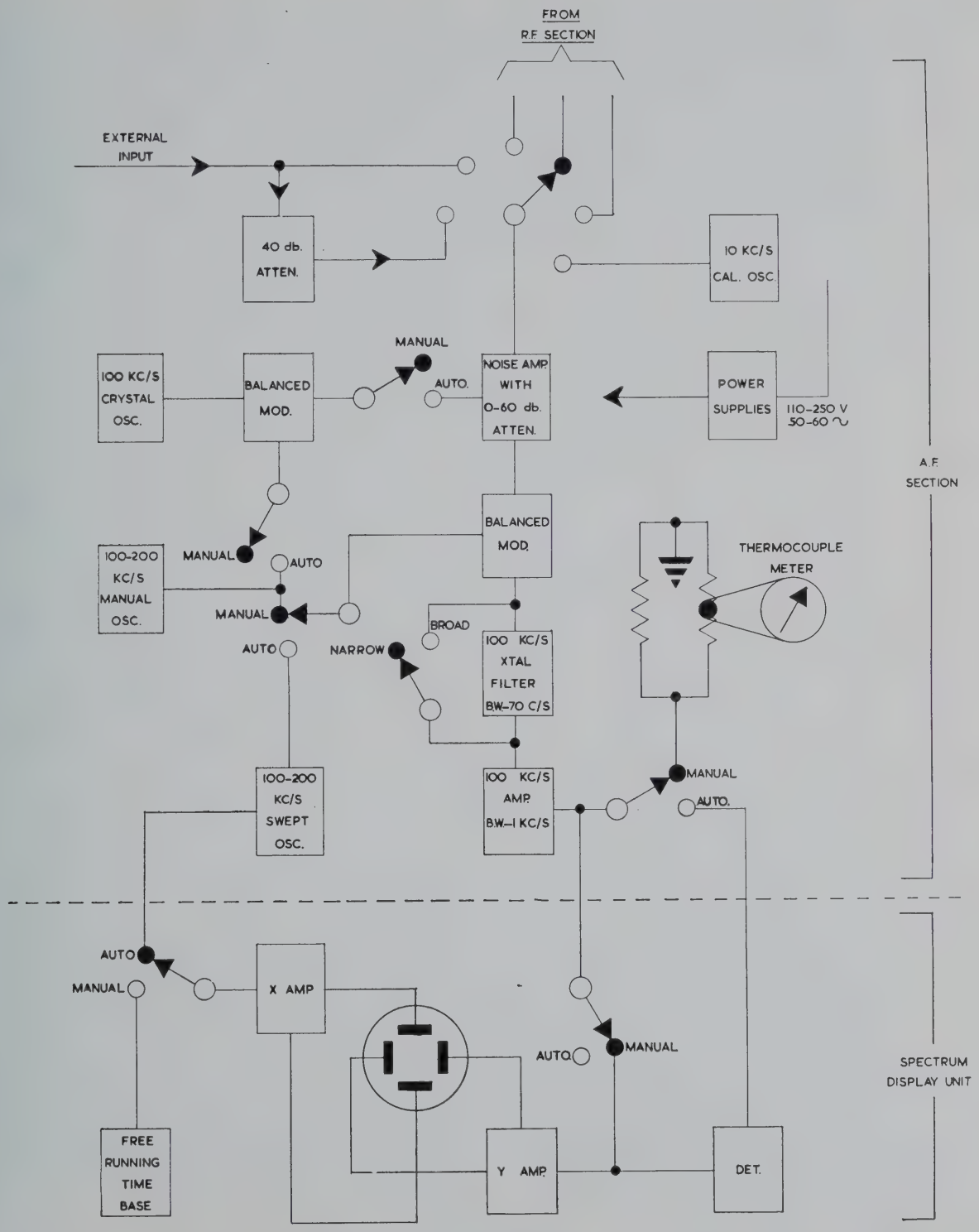


Fig. 2 Schematic diagram of Video Spectrum Analyser Type 190.

A visual display of this type provides qualitative information about the unknown spectrum, very rapidly and simply. The inherent weakness of such an elementary system is found in its lack of accuracy in the measurement of both amplitude and frequency.

1.3

Spectrum Analyser Type 190 successfully embraces the merits of both systems by combining an oscillographic, or panoramic display, with a power level indicating meter, which can be rapidly switched into operation and adjusted to permit accurate measurements of amplitude and frequency at any part of the spectrum.

1.4

Filters employed in wave analysers are generally either "constant percentage bandwidth" or "fixed bandwidth" types. Both have their particular advantages and disadvantages, depending on the nature of the required measurement. Specifically, a constant-percentage bandwidth analyser is most useful when the waveform to be analysed has a predominantly "line" spectrum as, for example, in the examination of acoustic or mechanical vibration phenomena. On the other hand, a noise—or combination of noise and line spectra—is difficult to interpret with this type of filter and a fixed bandwidth type is preferable. This is the technique employed in the Type 190 instrument, which is illustrated by the schematic diagram, Fig. 2.

2.0 GENERAL DESCRIPTION OF SYSTEM AND MEASUREMENT TECHNIQUE

2.1

Referring to Fig. 2, the incoming signal is first amplified and then fed to a wide-band mixer, the reference carrier into the mixer being derived from a tuned oscillator with a frequency range from 100.5-195 Kc/s. Sum and difference frequency components are generated in the mixer and appear as output signals which are coupled into a frequency selective amplifier centred on 100 Kc/s. Thus, only difference signals having frequency components within the pass band of the tuned amplifier (which is arranged for sharp cut-off beyond its range) are transmitted through to the final stages and measuring circuits of the equipment. For quantitative work, a manually tuned oscillator with the dial calibrated in terms of the video frequency is used to provide the mixer reference signal, and the output power in a 70 c/s* band of frequencies is determined by means of a thermocouple microammeter.

2.2

In order to permit qualitative visual examination of the spectrum, the manually tracked local oscillator of the Spectrum Analyser may be switched out of circuit and replaced by a sweeping oscillator covering the required difference frequency in two ranges, 0-7 Kc/s and 0-100 Kc/s. The local oscillator sweep voltage generator is also used to derive the X-sweep of an oscilloscope employed for viewing the spectrum.

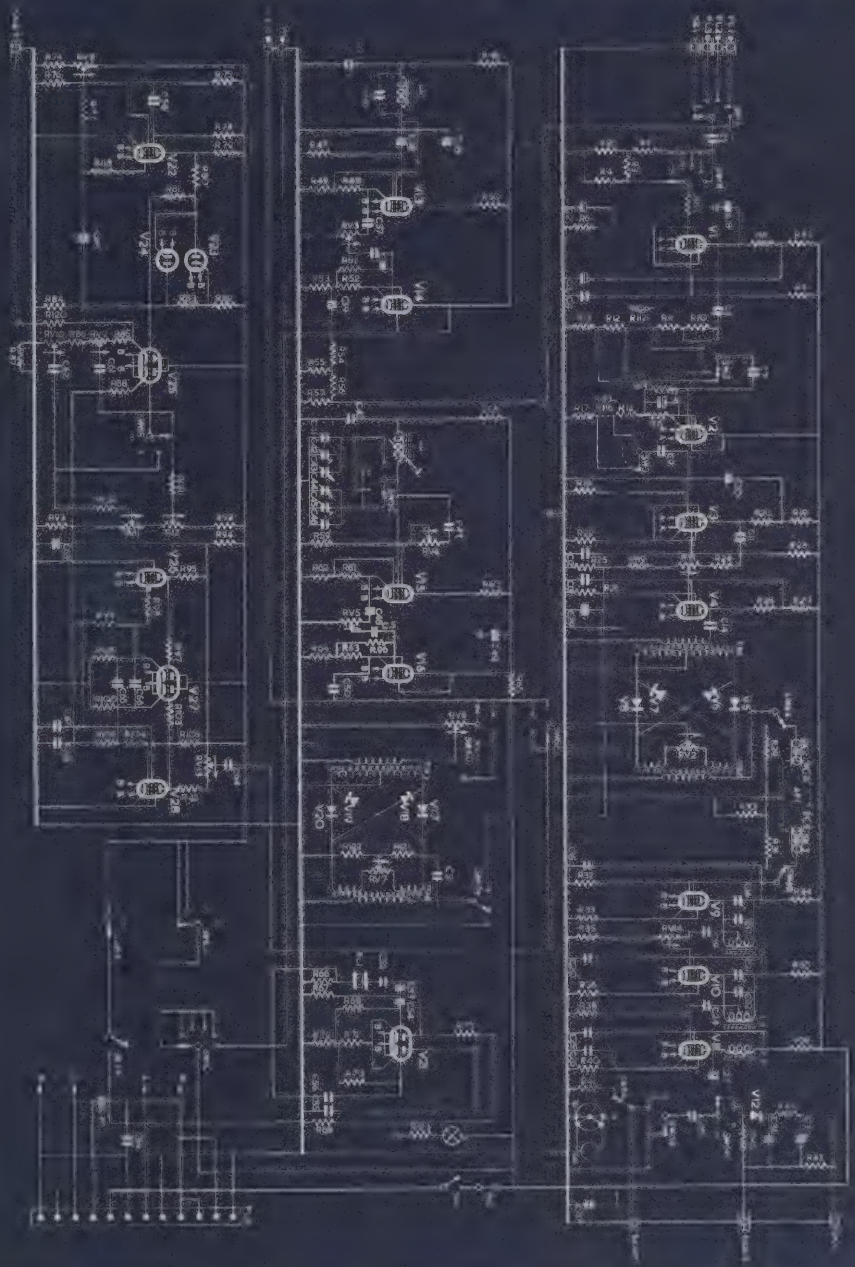
On the 0-7 Kc/s range, the 70 c/s band-pass amplifier is used, but the bandwidth is normally increased to 1 Kc/s for automatic sweep on the 0-100 Kc/s range in order to produce an easily read spectrum curve. The sweep rate is necessarily rather low, in order to avoid distortion and loss of signal through the narrow-band amplifier and it is, therefore, necessary to use a medium or long-persistence C.R. tube.

2.3

The time base is calibrated in frequency by a "marker" signal derived from the manual oscillator and coupled into the noise amplifier before the mixer circuit. The manual oscillator tracks over the range from 100-195 Kc/s and it is, therefore, necessary to use a second mixer to produce a lower sideband marker signal in the required range from 0.5-95 Kc/s. A crystal-controlled local oscillator is used as a reference in the marker frequency mixer. This method of deriving a marker signal has the particular advantage that once any particular "line" on the display has been identified by superimposing the marker "line" on it, very little further adjustment of the manual oscillator frequency dial is necessary to peak the meter reading on switching to "MANUAL," since the same oscillator is employed.

* See Section 8.0 for available alternatives.

FIG 3 CIRCUIT DIAGRAM OF SPECTRUM ANALYSER CHASSIS



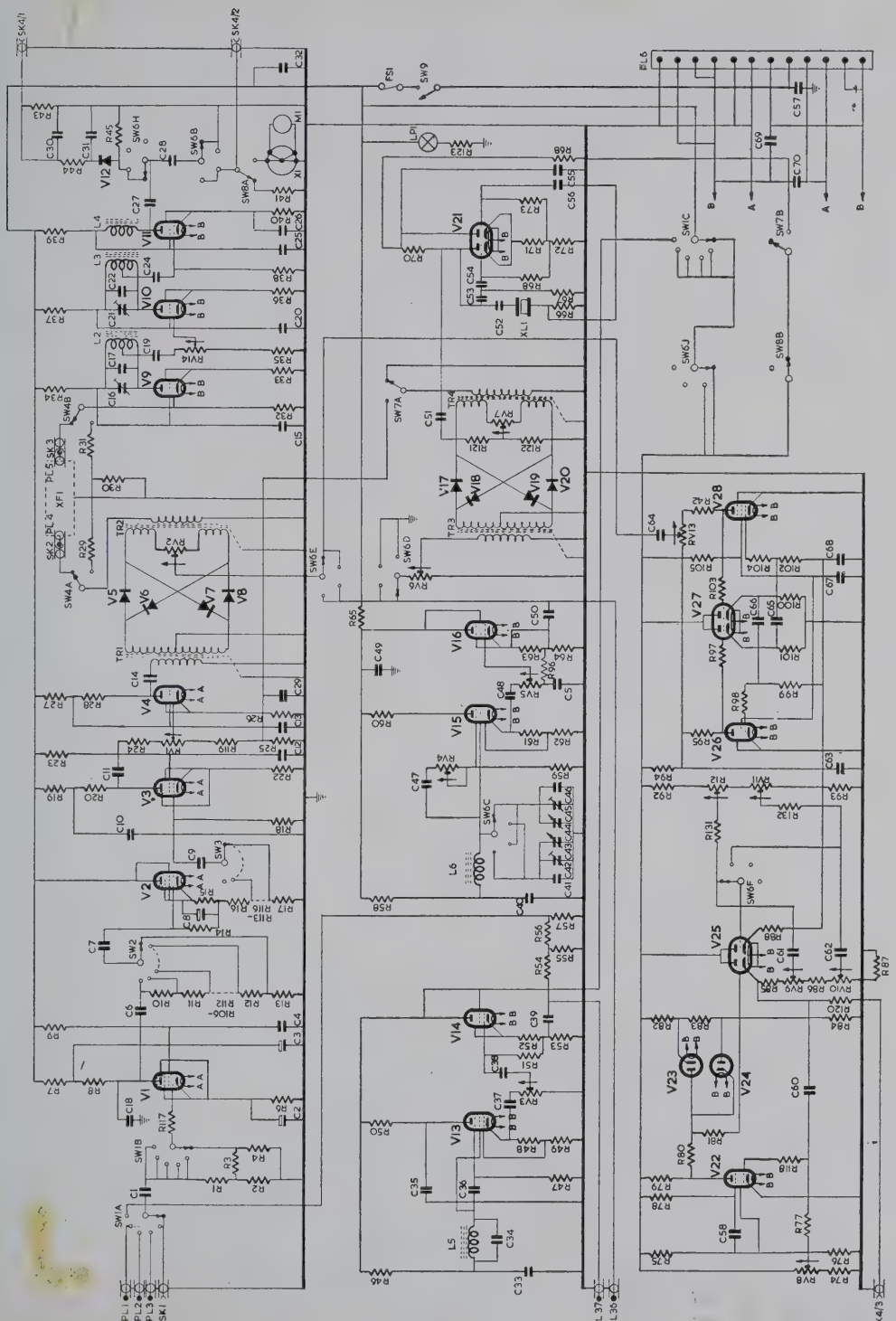


Fig. 3.

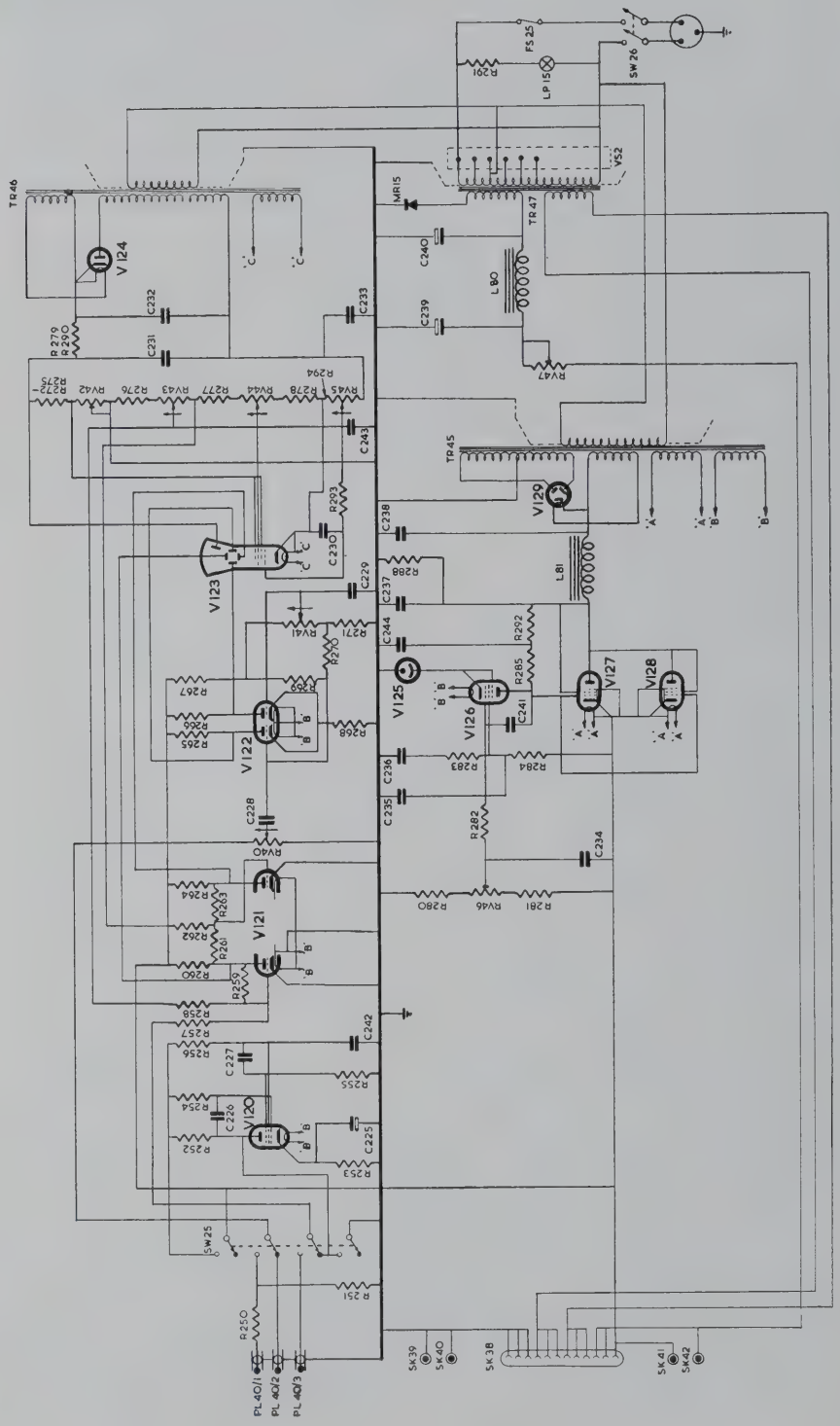
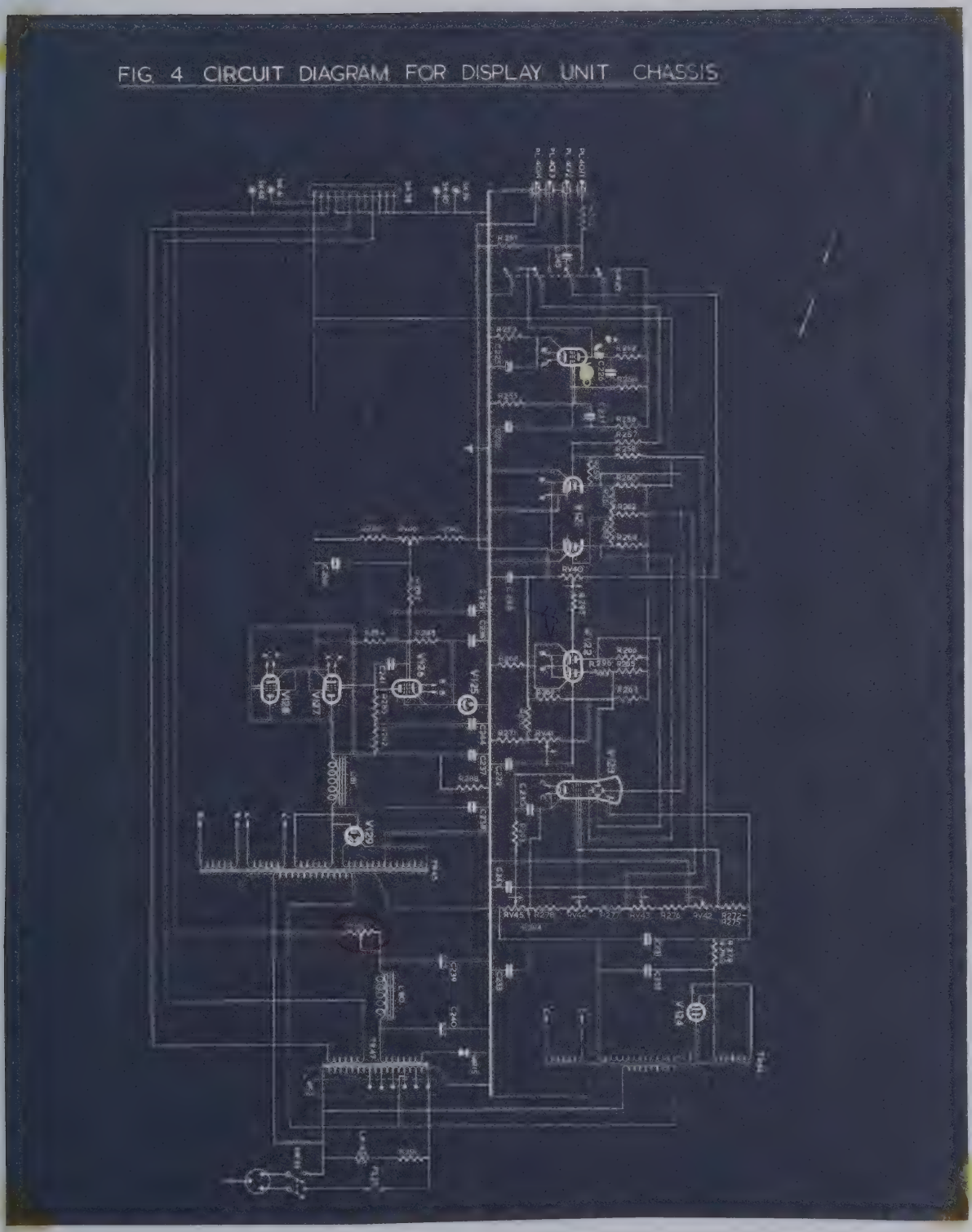


Fig. 4.

V122 Y Amp.

RVHT Pt. Number
Soldered

FIG. 4 CIRCUIT DIAGRAM FOR DISPLAY UNIT CHASSIS



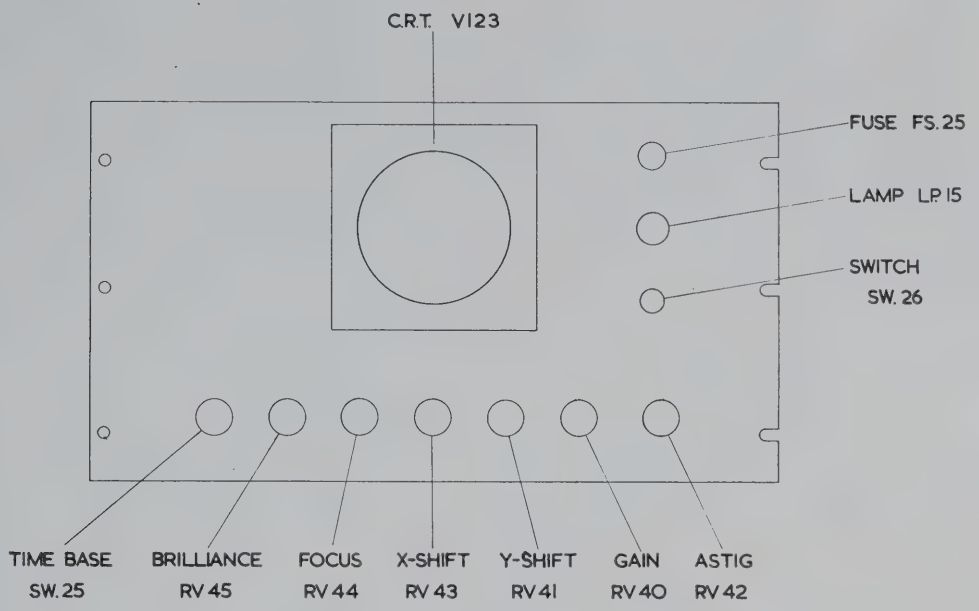


Fig. 5 (a) Layout of Display Unit.

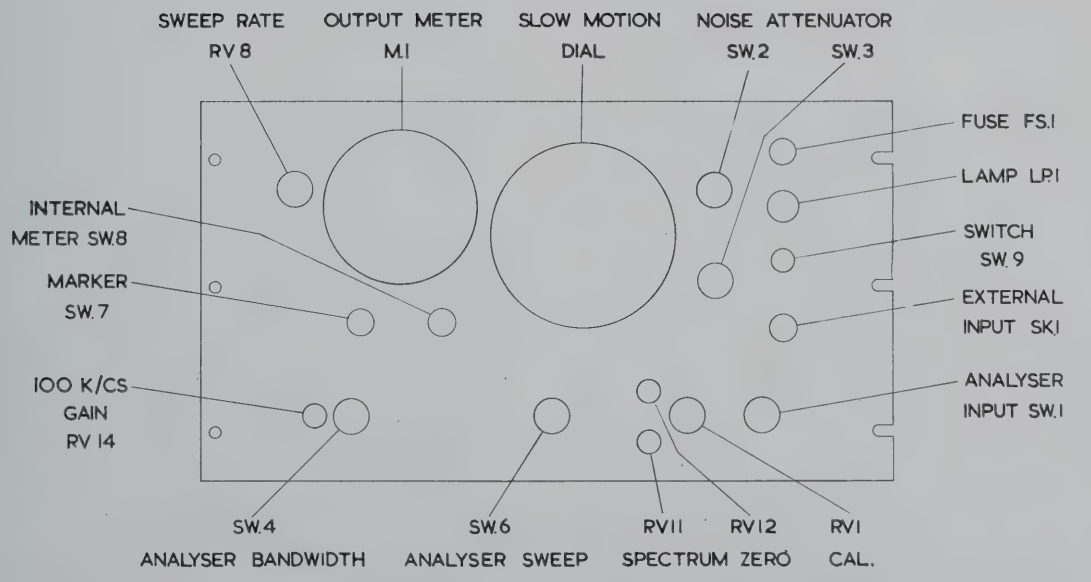


Fig. 5 (b) Layout of Spectrum Analyser Unit.

2.4

While the instrument is calibrated for a voltage measurement range of 100 db, the range of input levels (in terms of the amplitudes of the Fourier series components), which can be measured at the same time, lies between 50 db and 60 db, depending on the frequency separation between adjacent large and small signal components. This outstanding performance is obtained by the use of a comparison technique which ensures that :

(a) measurements are basically dependent only on the accuracy of a decade resistive attenuator, and,

(b) the use of the attenuator in the early stages of the noise amplifier ensures that subsequent circuits are not over-loaded.

In practice, the system sensitivity is adjusted with the decade attenuator switched to some convenient figure (i.e., mid-range position reads " 30 db ") and, by reference to a known level of input signal, which is obtained from a 10 Kc/s calibrating oscillator. The gain controls are changed to show a convenient deflection on the thermocouple milliammeter. All subsequent amplitude measurements are made by increasing or decreasing the decade attenuator setting, so that the output signal as first observed on the oscilloscope and next on the thermocouple meter gives the same reading or deflection as the calibration signal. For example, suppose in a particular instance the attenuator setting was found to be 16 db at a frequency of 53 Kc/s. The calibrating voltage level is 40 microvolts, so the amplitude of the signal components at 53 Kc/s is 14 db's down on 40 microvolts, i.e., 8 microvolt.

3.0 DETAILED DESCRIPTION OF SPECTRUM ANALYSER CHASSIS

A circuit diagram of the analyser is shown in Fig. 3 and the locations of major controls and components are given in Figs. 5 to 8.

3.1 Input Circuit

The six-way switch SW_1 enables the following input signals to be selected as required :—

Position 1—External input, voltage range approximately 1.0 microvolt to 10.0 millivolt.

Position 2—External input with 40 db attenuator (resistor network $R_1 - R_4$) inserted. This raises the input level range from 0.1 millivolt to 1 volt approximately.

Position 3—Sign detector signal. Only employed with external receiver for R.F. noise measurements.

Position 4—Reference Detector Signal. Only employed with external receiver for R.F. noise measurements.

Position 5—Signal Detector Signal. Only employed with external receiver for R.F. noise measurements.

Position 6—Standard 40 microvolt calibrating signal at 10 Kc/s fixed frequency.

3.2 Noise Amplifier

The amplifier stage comprising circuits V_1, V_2, V_3 and V_4 is designed to have a flat response characteristic over the frequency range 500c/s-90 Kc/s.

Since the frequency of the IF is 100 Kc/s, it is necessary to ensure sharp cut-off in the amplifier response before this frequency is reached. A typical characteristic is shown in Fig. 9.

It has been mentioned (Section 2.4) that all quantitative measurements are made by employing calibrated attenuators to adjust the measured power output to a standard level, the amplifier having previously been adjusted in sensitivity to indicate the same standard level against a known calibrating signal. As with all similar comparative measurements, the accuracy achieved is independent, for practical purposes, of relatively large changes in the absolute sensitivity of the instrument and therefore it is possible to make useful measurements at frequencies outside the range of flat amplifier response, i.e., below 500 c/s and above 90 Kc/s, providing a correction is applied to the indicated level, to allow for the reduced sensitivity of the amplifier. The required correction at any frequency can be obtained from Fig. 9 and in practice it will be found that useful measurements can be made over a frequency range 200 c/s to 95 Kc/s. Beyond these frequency limits the use of the instrument is limited not only by the reduction in sensitivity but also by " breakthrough " at 100 Kc/s arising in the signal or in the heterodyne oscillator.

The first two tubes in the noise amplifier are chosen for low noise and microphony, and

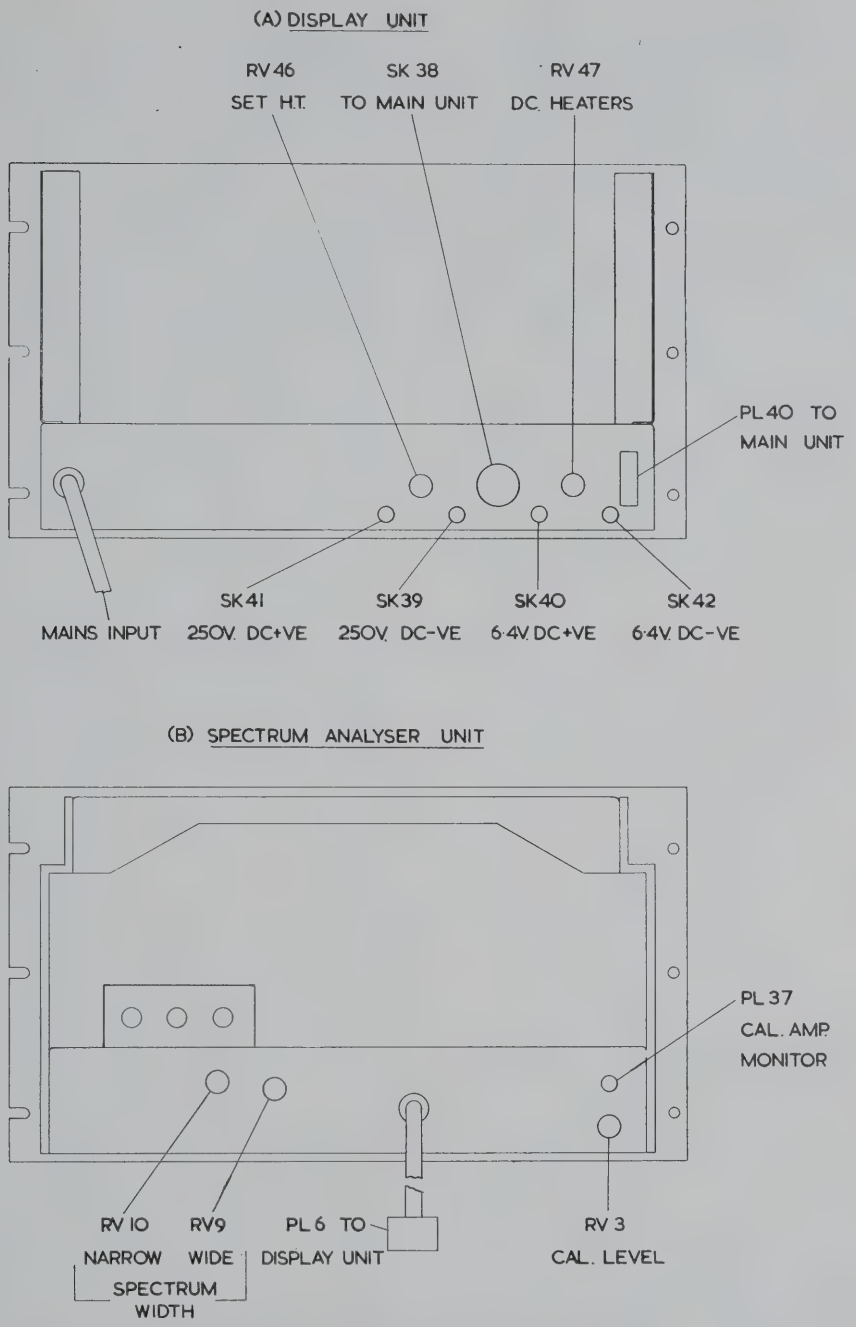


Fig. 6 Rear Panel Layout of Instrument.

in practice the inherent noise level is approximately 0.2 microvolt, referred to the input terminals out of a source with a resistance of 5 kilohms.

The output from the first stage V_1 is connected to an attenuator providing 5 × 10 db gain steps via SW_2 to the grid of the cathode follower V_2. The load of this stage is a further attenuator providing 10 × 1 lb steps via SW_3 to the final amplifier and output stages V_3 and V_4. An uncalibrated variable attenuator RV_1 coupled between these two stages has a range

of 6 db and enables the overall sensitivity to be standardised with reference to the calibration signal (see Section 5.3).

Apart from the usual advantages of employing what is commonly known as a "substitution" method of measurement, there are even stronger reasons for doing so in this particular case. In particular, the possibility of overloading by line or noise peaks in later stages of the apparatus are strongly reduced. Final measurements are made by means of a thermocouple millammeter and involve RMS levels of not greater than 1.0 volt at the output of the selective 70 c/s IF amplifier, but there is no bandwidth limitation prior to the crystal filter other than that imposed by the noise amplifier response. Thus, it is important to have the means for limiting the sensitivity to prevent overloading the later stages of the noise amplifier and the following modulator or mixer stage.

3.3 Signal Mixer

After amplification, the signal is fed to a mixer circuit supplied with a biassing voltage from a local oscillator with a frequency range from 100.5-195 Kc/s.

The signal mixer is a double balanced modulator using four crystal diodes in a conventional bridge-ring arrangement. The output stage of the noise amplifier is matched to the input transformer TR_1 of the modulator and the output transformer TR_2 is matched to the input of the 100 Kc/s filter XF_1.

A double balanced modulator is employed to ensure isolation from 100 Kc/s noise signal components which would otherwise pass directly through the 100 Kc/s filter (see Section 3.7), and also to suppress local oscillator signal components which would similarly tend to break through as the local oscillator frequency approached 100 Kc/s.

A variable potentometer RV_2 enables the modulator to be balanced, as described in Section 6.3, and in practice the degree of isolation achieved is of the order of 40 dbs.

3.4 Signal Mixer Drive

Depending on whether or not the equipment is being used on "automatic sweep" (panoramic display) or on "manual" in conjunction with the thermocouple milliameter, M_1, the biassing drive to the modulator is derived from either the swept oscillator, V_{26}, V_{27}, V_{28} or the manually tuned oscillator V_{15}, V_{16}.

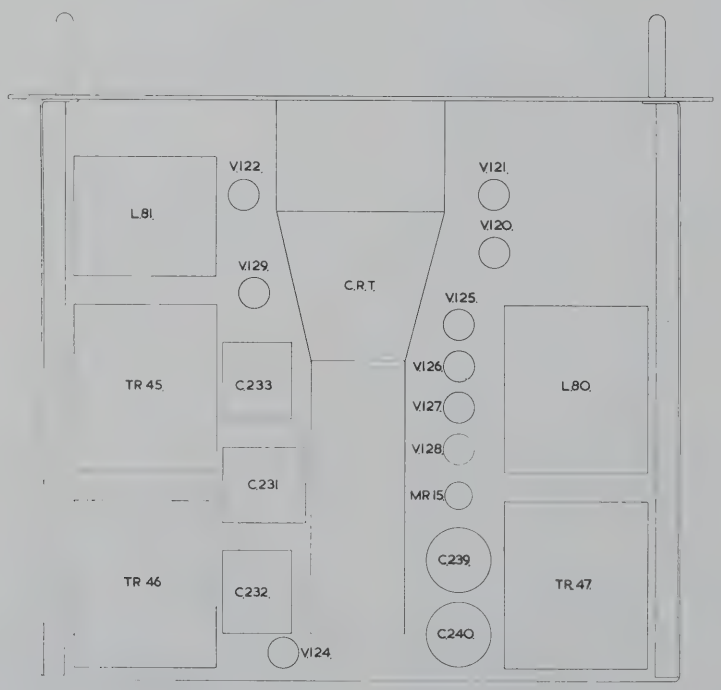


Fig. 7 (a) Component Layout of Display Unit—Top View.

In either case, two frequency ranges are available which, in terms of the difference or lower sideband frequencies correspond to 0-7 Kc/s and 0-100 Kc/s, and these may be selected by switch SW_6, as required.

3.5 Manual Oscillator

This comprises a tuned grid, LC transitron oscillator V_{15} followed by a buffer stage V_{16}.

With the switch wafer SW_{6b} turned to position 4, the oscillator will tune through the range 100-110 Kc/s and on position 3 the range is 100-200 Kc/s.

In both cases, tuning is capacitive by means of C_{43} and C_{44}. Both are driven from the same shaft and the dial is calibrated in two ranges in terms of the **lower sideband** or difference frequency of the mixer, i.e., signal frequency, from 0.5 Kc/s to 7 Kc/s and from 1 to 100 Kc/s.

In addition to the function of supplying the signal mixer drive on "Manual," the oscillator is used in the "Auto" condition to generate a frequency marker line (or more correctly, "blip"), on the panoramic display for frequency calibration purposes. Thus the two frequency ranges are repeated on positions 1 and 2 of SW_{6b}.

In order to generate a frequency marker by means of the manual oscillator, it is necessary to employ a further mixer V_{17}-V_{20}, which derives its switching frequency from a 100 Kc/s fixed frequency crystal controlled oscillator V_{21}. The output from this mixer is then coupled into the noise amplifier at the junction of resistors R_{19} and R_{25}. For example, suppose the manual oscillator is tuned to 110 Kc/s, so that the dial reading is 10 Kc/s; then, the signal out of the mixer will comprise principal sum and difference components of 210 Kc/s and 10 Kc/s together with subsidiary sidebands arising from oscillator harmonics. In practice, these are negligible and the upper sideband is outside the response of the instrument. It follows that the marker signal is a single frequency component which appears as a line superimposed on the signal spectrum of the subsequent panoramic display.

This method of frequency calibration has two very distinct advantages. In the first place, the same oscillator is used both to derive the marker line and subsequently to provide the bias to the signal mixer on the manual tuning. This means that once any particular line of interest in a signal spectrum has been lined up to the frequency marker, then subsequently switched to manual, little or no further adjustment of the tuning control will be necessary in order to obtain the maximum power figure corresponding to the line. Secondly, the accuracy of frequency calibration cannot be affected by factors such as linearity of the frequency base and changes in the spectrum width swept out by the panoramic display circuits.

3.6 Swept Oscillator

When the equipment is switched to "Auto" on positions 1 and 2 of SW_6, the manual oscillator drives the marker mixer, as described in the previous section, and the drive to the signal mixer is taken from the "swept" oscillator which has two tuning ranges, from 100-110 Kc/s and from 100-200 Kc/s.

The swept oscillator comprises a free-running multivibrator V_{26}, V_{28} with cathode followers $V_{27a,b}$ interposed between the anode and grid feedback circuits in order to maintain the output amplitude constant and fast rise time over the frequency range. The signal mixer drive is obtained from a variable tap on RV_{13} connected differentially between the anode loads.

Tuning of the multivibrator is effected by varying the grid bias levels symmetrically by means of a sawtooth waveform developed by the sweep generator, V_{22}-V_{25}.

V_{22} is an orthodox phantastron timebase circuit with the maximum and minimum voltage excursions determined by limiting action on diodes V_{23} and V_{24}.

Sweep rate is variable by means of RV_8 from (0.5 Sec./Sweep) to (5.0 Sec./Sweep).

The spectrum width on the narrow and wide spectrum ranges may be adjusted by means of the potentiometers RV_{10} and RV_9; and the "zero" adjustments RV_{11} and RV_{12} are preset controls to enable the commencement of the panoramic sweep to be set to 100 Kc/s on both ranges.

The output from the cathode follower V_{25} drives the swept oscillator and is also taken through coupling capacitor C_{57} to coaxial connector SK_8 and from this point to the display unit in order to drive the oscilloscope timebase.

3.7 100 Kc/s Amplifier

The output from the signal mixer, which has been described in Section 3.5, is connected via switch contact SW4a to the 100 Kc/s amplifier and output circuits. With the switch in position 1, the input signal is taken through a narrow-band crystal filter XF_1, having a noise band-

width of 70 c/s and characteristic response as indicated in Fig. 10. Stages V_9, V_{10} and V_{11}, together comprise a selective amplifier with a centre frequency of 100 Kc/s, a noise bandwidth of 1 Kc/s and a gain of 90 db's.

It follows that when the switch SW4a is turned to position 1 the effective bandwidth of the 100 Kc/s amplifier is 70 c/s, but in position 2 the effective bandwidth is 1 Kc/s. The attenuator pad, comprising R_{29}, R_{30} and R_{31}, represents the attenuation which is introduced by the filter XF_1 and so ensures that the effective gain of the selective amplifier is held constant for both bandwidth conditions.

When the display selector switch, SW_6, is set to the "Auto" condition, the output from the

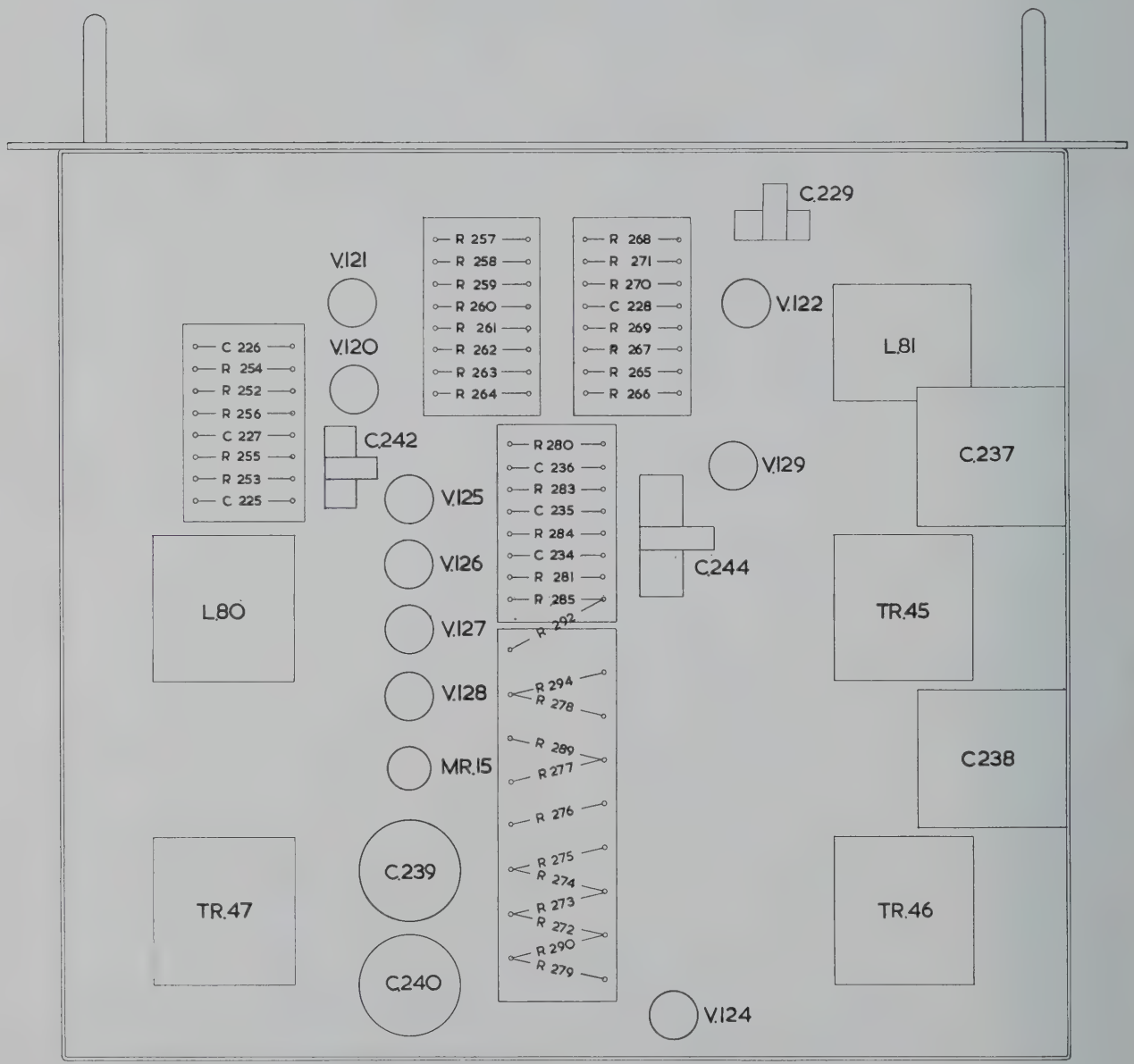


Fig. 7 (b) Component Layout of Display Unit—Bottom View.

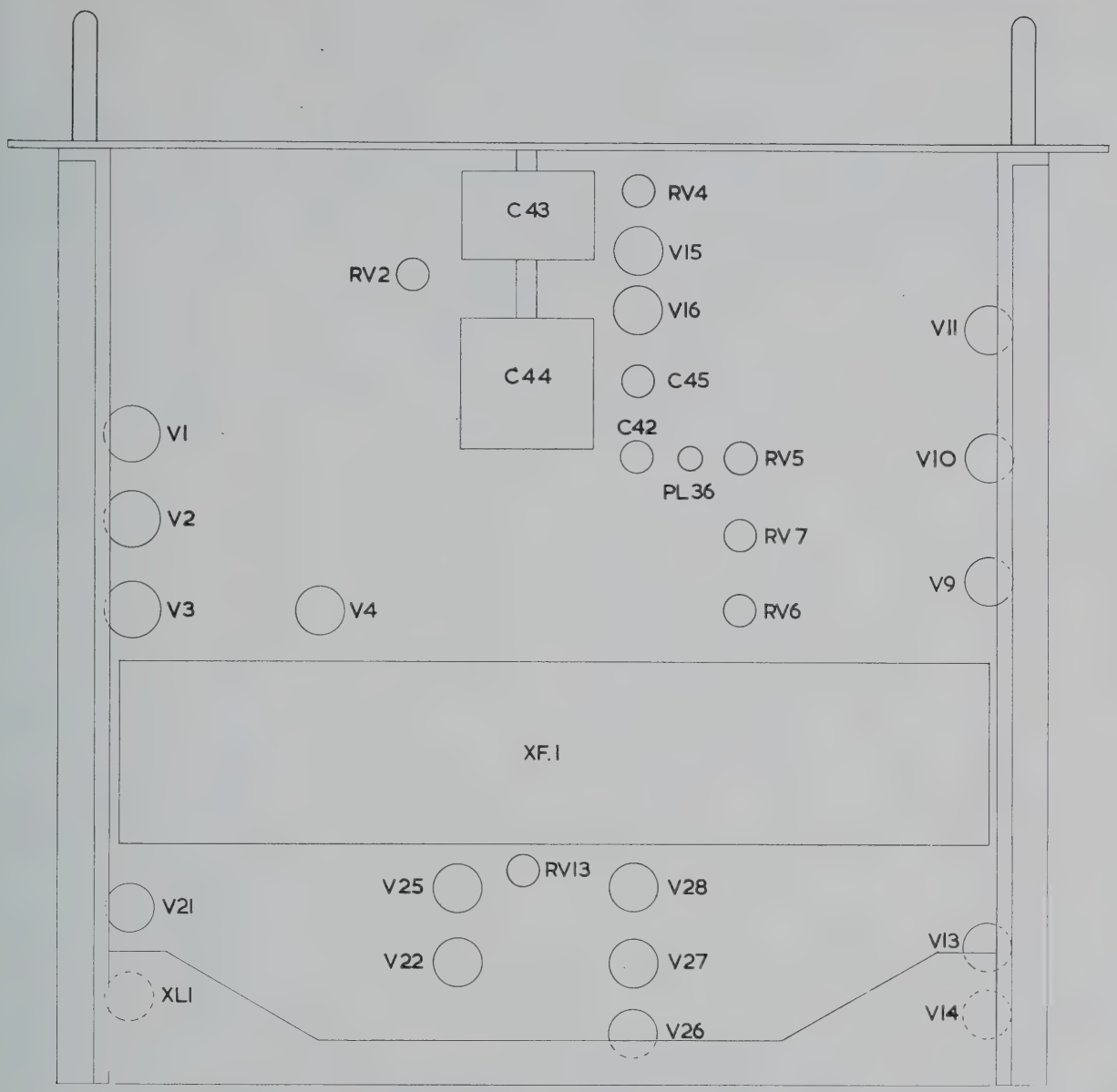


Fig. 8 (a) Component Layout of Spectrum Analyser—Top View.

100 Kc/s amplifier is taken via C_{27} to the linear detector, V_{12}, and so to the output socket, SK_4. From this point, it is taken via a short length of coaxial line to the "Y" amplifier of the display unit. If, on the other hand, SW_6 is turned to the "Manual" position, the amplifier output is taken via C_{28} to the vacuo junction X_1 and the thermocouple output from this component is displayed on the moving coil milliameter M_1. At the same time, the signal is connected through to coaxial socket SK_5 and thence to the display unit.

3.8 Calibration Oscillator

A 1 amplitude measurements of signal or noise power are made with reference to a 10 Kc/s signal generated by the calibration oscillator V_{13}. The output from this oscillator is taken via the calibration level control RV_3 through cathode follower V_{14}. The level control is adjusted so that the calibration signal level monitored at socket SK_6 is 400 millivolt which thus ensures that a 40 microvolt signal is developed across R_{57}.

Note—This signal should not be used for frequency calibration.

4.0 DESCRIPTION OF DISPLAY UNIT

4.1

The display unit panel assembly contains power supplies for the complete equipment, X and Y amplifiers, the circuits associated with the cathode ray tube V_{123}, and a single valve time base sweep generator for use on "Monitor." A circuit diagram is given in Fig. 4.

The circuits employed are conventional and there is, therefore, little need for a detailed description. The following gives the functions of the various circuits in convenient tabular form :—

4.2 Summary of Circuit Functions

Tube Ref.	Tube Types	Circuit Function	Associated Variables.	Remarks
V120	EF91	" Monitor " Timebase sweep generator.		Used with SW25 switched to " Monitor."
V121	12AT7	" X " Amplifier	RV43—X-Shift	
V122	12AT7	" Y " Amplifier	(a) RV40—Gain control for Y sensitivity. (b) RV41—"Y" Shift.	
V123	4EP7	CRO	(a) RV45—"Brilliance " (b) RV44—"Focus." (c) RV42—"Stig " (controls astigmatism).	
V124	R10	EHT Rectifier		
V125 V126 V127 V128 V129	85A2 EF91 N78 N78 EZ81	Stabilised H.T. line voltage.	RV46—"Set H.T."	Output Level 250V to ground (H.T. negative rail). Check at monitor points SK41 (positive) and SK39 (negative).
—	—	D.C. Heater Supply	RV47 "D.C. Heaters"	Enables heater levels to be adjusted to 6.4V at output monitor points, SK40 (positive) and SK42 (negative).

NOTE : Monitor probe points are located at the rear of the chassis.

4.3 Power Output Services

Summary of power supplied by display unit for operating Spectrum Analyser chassis :—

Supply	Pin Ref. on output connector SK38 (at rear of chassis)
250V regulated line voltage mA	A —Positive B. F & K—Negative (linked)
6.4V D.C. Heater supplies —A	J. & E (linked)—Positive B. F & K (linked)—Negative
6.3V A.C. Heater supplies —A	D, H & M (linked)—Line 1 C, G & L (linked)—Line 2

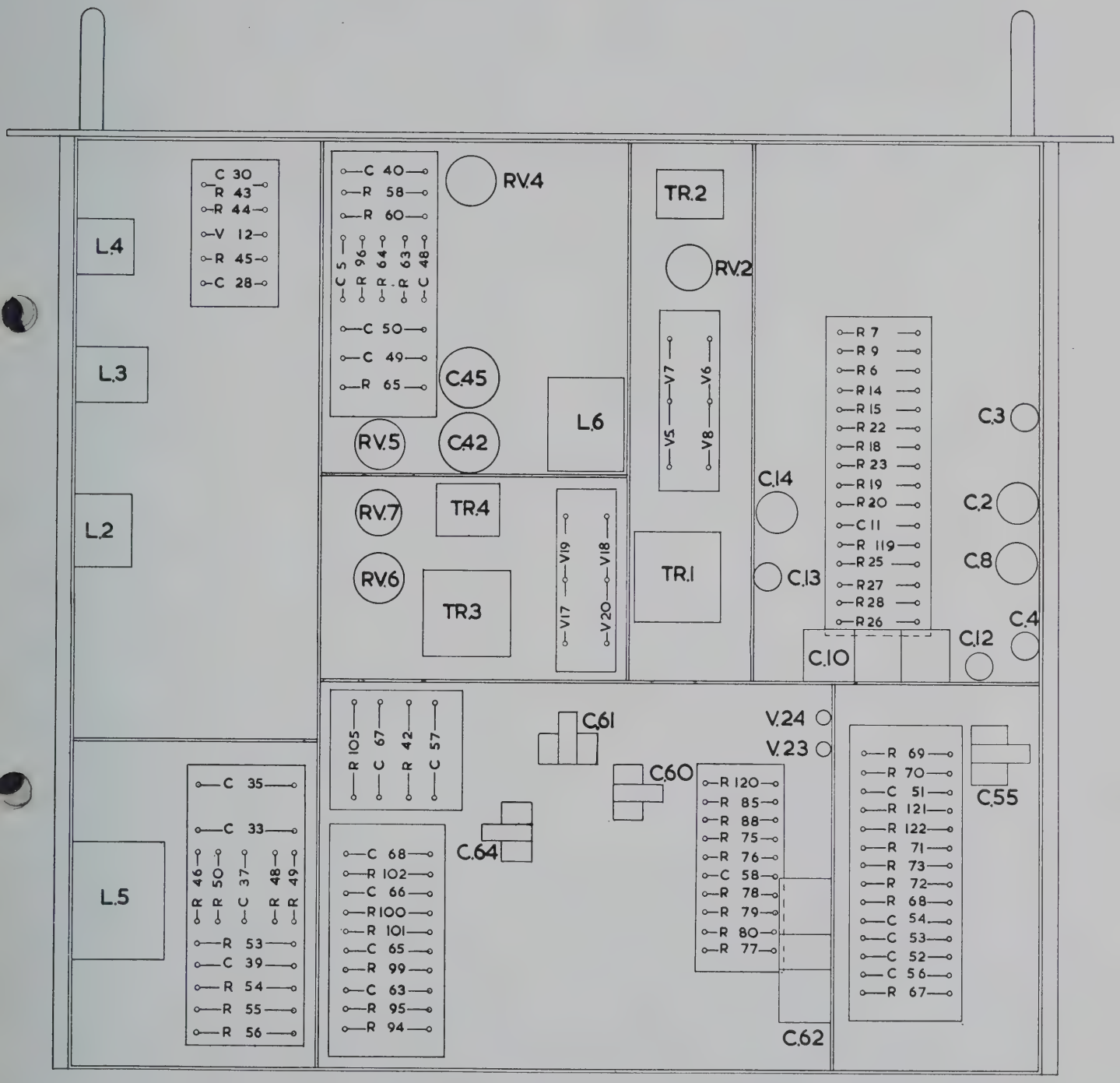


Fig. 8 (b) Component Layout of Spectrum Analyser Unit—Bottom View.

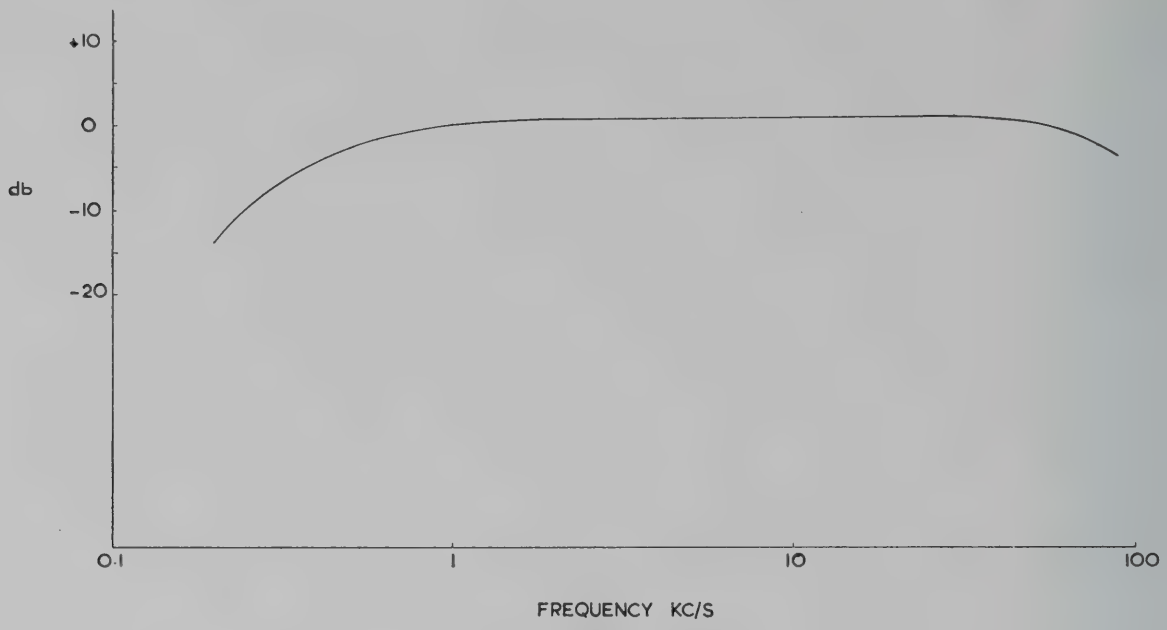


Fig. 9 Noise Amplifier Response.

5.0 GENERAL SETTING-UP INSTRUCTIONS

MAINS VOLTAGE SELECTOR

5.1 Check Supplies

On the rear of the display unit chassis there are two sets of monitor sockets, engraved 250V D.C. and 6.4V D.C., respectively. Check that these are correct and, if necessary, adjust with the adjacent controls.

5.2 Set the Spectrum Analyser on "MANUAL"

Switch range switch to 1-100 Kc/s "MANUAL."

Switch input selector switch to "CAL."

Switch filter selector switch to "70 c/s."

Switch decade attenuators to 30 db's.

Switch display unit selector switch to "MONITOR."

Adjust "Y" gain control so that the engraved line on the knob coincides with the line engraved on the panel.

Adjust "Y" shift control until the trace is central, i.e., coincides with the centre line engraved on the tube screen.

5.3 Check Calibrating-Oscillator Level

Check output at SK_6 on rear of spectrum analyser chassis, using a valve voltmeter or calibrated oscilloscope. The output should be 400 mV RMS. Adjust for this level with RV_3. This signal is connected via a fixed 80 db's attenuator to the input and thus provides a 40 microvolt calibrating signal.

5.4 Check Spectrum Analyser on "MANUAL"

Tune the manual oscillator slowly in the region of 10 Kc/s for maximum output in the oscilloscope. Adjust this output with the decade attenuators until the engraved lines on the oscilloscope tube faces are filled. Press the thermocouple meter switch and note the reading. This should be about 2 mA but can be set to this, or any convenient value, using the "CAL" control. Do not press the meter switch if the output on the oscilloscope exceeds the value quoted above, or the thermocouple may burn out. The spectrum analyser is now calibrated for an input signal of 40 microvolts and all subsequent measurements are made using this as a basis for calculation.

5.4.1 Extending the Range

If the instrument is calibrated, as outlined above, with the decade attenuators reading 30 db, it follows that the range of signals which can be measured directly is ±30 dbs on 40 microvolts. This range can be extended by 40 dbs in the positive direction by switching to the "40 db" position on the selector switch

and by at least 10 dbs in the negative direction by calibrating for a lower output, i.e., setting the attenuators to 40 dbs and noting the new output figure. The range of the instrument will now be −40 to +60 dbs on 40 microvolt, which is 0.4 microvolts to 40 millivolts. Thus, any signal in the range 1-90 Kc/s and of RMS level between 0.4 microvolt and 40 millivolts can be accurately measured by setting the attenuators for the noted output level on the meter or, less accurately, by observing the level on the display unit. In this manner, by adjustment of the sensitivity level, the range may be changed to enable signal levels in the range 0.1 microvolt to 1.0 volt to be measured.

Signal levels outside the specified frequency range, i.e., 200 c/s-1 Kc/s and 90-95 Kc/s, may also be checked by referring to the response characteristic of the amplifier (see Fig. 9).

5.4.2 Check Filter Attenuator Pad

When the spectrum analyser is calibrated, switch the filter selector to "1 Kc/s." There should be no appreciable change in output level.

5.5 Check Spectrum Analyser on "AUTO"

Switch range selector to 1-100 Kc/s "AUTO."

Switch input selector switch to "Direct Input."

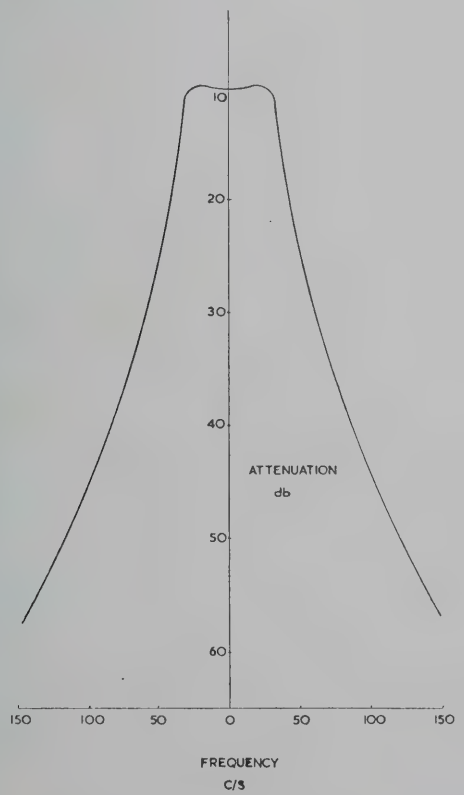
Switch filter selector switch to "1 Kc/s."

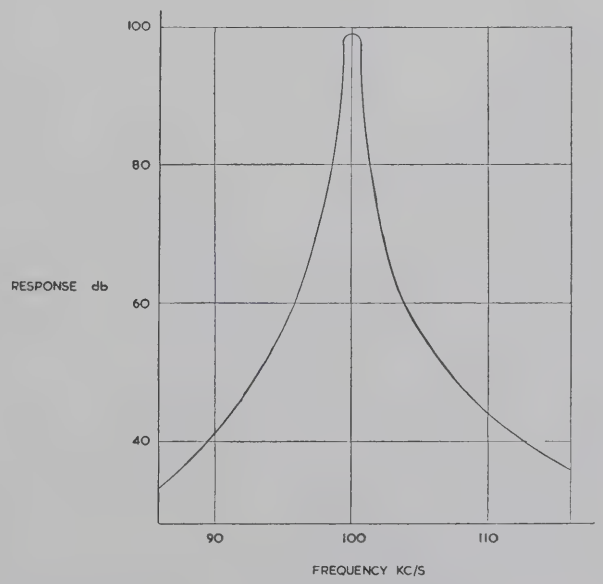
Switch display unit input selector switch to "SPECTRUM."

Set "Y" gain to maximum.

5.5.1 Set Spectrum "ZERO"

With the switches in the above position, there should be a slow sweeping trace on the tube. Towards the left-hand side of the trace there should be a signal due to 100 Kc/s breakthrough caused by residual unbalance in the signal modulator. This is the zero frequency point and can be set to any desired position on the trace by adjusting the appropriate "SET ZERO" control on the Spectrum Analyser front panel. It is normally set to be just off the left-hand side of the trace. If the breakthrough signal is not visible, the "SET ZERO" control should be turned clockwise slowly until it appears. (CAUTION: A fine "touch"





Figs. 10 and 11.

should be used in adjusting these controls, since a long coupling time constant results in sluggish response).

5.5.2 Set Spectrum Width

The spectrum width can readily be determined using the " marker pip." Set the manual oscillator at 5 Kc/s. Press the marker switch and observe that a signal now appears quite near the left-hand side of the trace. Increase the frequency of the manual oscillator and note that the signal follows, moving along the trace to the right. The signal should be just visible at the extreme right of the trace at maximum frequency, i.e., 95 Kc/s. If the signal has disappeared, or has not reached the end of the trace, the width can be adjusted with the control, RV_9, at the rear of the Spectrum Analyser chassis.

5.5.3 Performance on "Auto" (0.5-100 Kc/s)

With the spectrum analyser operating as outlined above, switch the decade attentuators to 0 db and inject a signal (source impedance not greater than 5 Kc/s) in the range 1-90 Kc/s and at a level of 1 microvolt. This signal should be clearly visible and of approximately twice the amplitude of the inherent noise, which will now be visible on the trace.

5.5.4 Performance on "Auto" 0.5-7 Kc/s

Repeat 5.5.1-5.5.3 with range selector switch on 1-7 Kc/s " AUTO " and filter selector switch on 70 c/s. Note that 1-7 Kc/s spectrum width control is RV_{10}, adjacent to RV_9.

5.5.5 Sweep Speed

There is a sweep rate control, RV_8, on the rear of the spectrum analyser chassis, which adjusts the sweep speed in the range 2 sweeps per second, to 5 seconds per sweep.

5.5.6 Making a Measurement

Inject a signal as at 5.5.3, for example, at 20 Kc/s. Press the marker switch and adjust the manual oscillator until the marker coincides with the input signal. Release the marker switch and set all switches as for manual operation. There should be some output visible on the oscilloscope. Adjust the manual oscillator for maximum and set this to the original " CAL " level with the decade attenuators. The amplitude of this signal can now be computed directly from the attenuator reading.

6.0 TEST AND CALIBRATION PROCEDURES

6.1 Measurement of Limiting Sensitivity

First, adjust and calibrate the equipment, as described in Section 5.0.

6.1.1 Performance on " MANUAL "

Operating the spectrum analyser as outlined above, and with the decade attenuators switched to 0 db, inject a signal from an external source in the range 1-90 Kc/s, at a level of approximately 1 microvolt. This signal should be clearly visible when the manual oscillator is tuned for maximum output. Adjust this signal to double the mean output level under " no signal " conditions. The input signal is then at the limiting sensitivity of the system. This should be approximately 0.2 microvolt, but the precise figure depends on the signal frequency and the input impedance.

6.1.2 Performance on "AUTO "

This may be determined by a similar procedure to that outlined in Section 5.5.3 above, but using the panoramic display. In general, the noise performance is somewhat poorer under these conditions.

6.2 Check Gain-frequency Characteristic of Noise Amplifier

Using " external input," inject the output from a signal generator with frequency range 1-100 Kc/s at a suitable level, so that the thermocouple meter reads approximately 2 mA with the attenuators set at 35 db. Plot change in frequency versus change in attenuator reading, ensuring that the input remains constant. The amplifier should be flat within ±1 db over the range, 1-90 Kc/s, but useful measurements with some decrease in accuracy can be made over a wider range, as will be seen by examination of the typical response curve of Fig. 9.

Corrections to the measured results can also be made by referring to this calibration, if necessary.

If the measured response fails to meet the standard quoted, then a fault should be sought. A useful check is to transfer the input signal to the primary winding of the modulator and thus check whether this circuit has the correct response.

6.3 Local Oscillator Balance .

The signal modulator is a double balanced modulator using CV.448 diodes. The purpose of using the balanced circuit is to achieve rejection from 100 Kc/s components in the signal input which would otherwise pass directly through the 100 Kc/s filter, and also to provide isolation from the local oscillator input when its frequency approaches 100 Kc/s.

The local oscillator balance factor is defined as the ratio of the local oscillator input at 100 Kc/s required to produce a certain output to the signal input at 100 Kc/s required to produce the same output when the local oscillator is tuned to 200 Kc/s and the output level set to 400 mV r.m.s. The method of adjustment is as follows :—

(a) Tune the manual oscillator to 100 Kc/s with no signal input. Observe output at monitor oscilloscope and adjust for minimum with the local oscillator balance control. Note this output.

(b) Now tune local oscillator to 200 Kc/s and inject 100 Kc/s signal at input terminals, Adjust 100 Kc/s input signal for the same output level as before. It is convenient to use the decade attenuator for this test.

The ratio of measurments A:B then gives the local oscillator balance factor directly and is of the order of 40 db. The normal working level of the local oscillator is 400 millivolts RMS.

6.4 Narrow-Band Filter

The response characteristic of the narrow-band filter determines the selectivity of the whole system. Since one of the functions of the spectrum analyser is to enable noise powers to be measured accurately, the filter has a response curve shaped so that it corresponds very closely to the ideal rectangular form. A typical curve is shown in Fig. 10.

6.5 Selective Amplifier

For fast spectrum sweep rates, the attenuation introduced by the 70 c/s filter is too severe to enable small signal components to be observed. The IF amplifier is, therefore, arranged to have a noise power bandwidth of approximately 1 Kc/s and the 70 c/s filter can be switched out of circuit for automatic scan on the 100 Kc/s range.

A typical response curve is given in Fig. 11 and the following tests can be made to check performance.

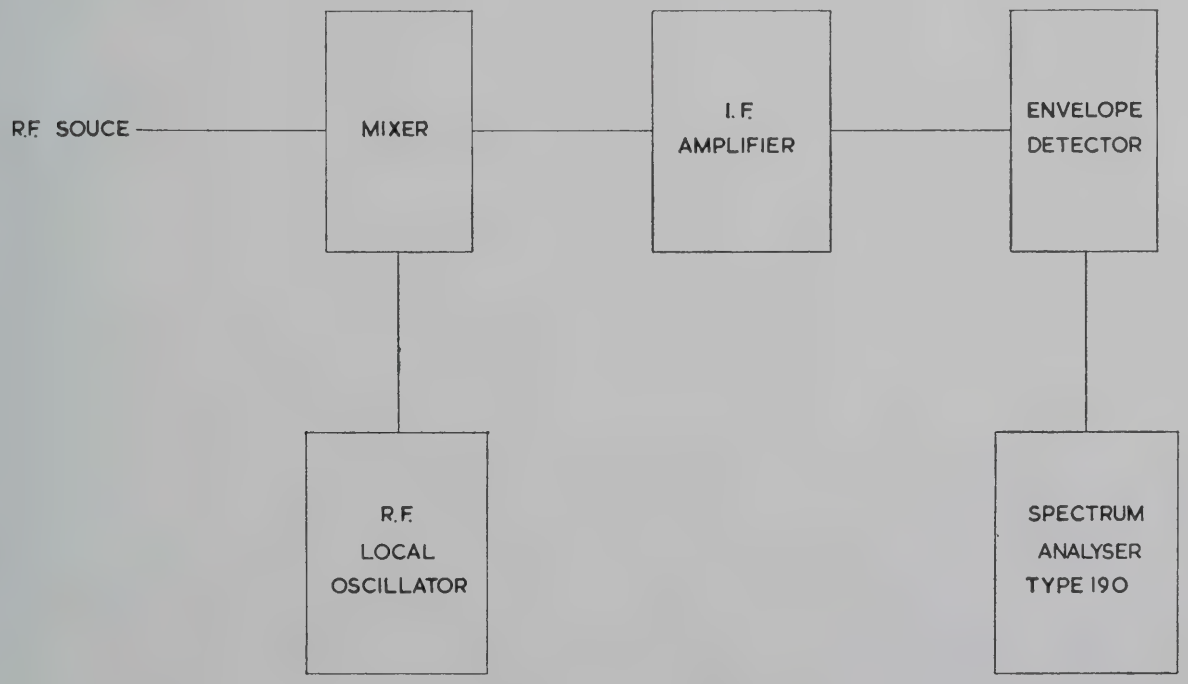


Fig. 12.

(a) **Check 3 db Banwidth of 100 Kc/s Amplifier**

This test can be satisfactorily performed using the spectrum analyser as a monitor. Inject a signal of suitable amplitude in the 1-7 Kc/s range at, say 4 Kc/s. With the filter selector switch set to 1 Kc/s, tune manual oscillator for maximum. Note output and frequency. Increase spectrum analyser gain by 3 db's. Swing manual oscillator dial on either side of original reading, until output returns to noted figure. These figures will give the 3 db bandwidth which should be 700-800 c/s.

(b) **Noise Power Bandwidth of 100 Kc/s Amplifier**

The 3 db figures shown above have been chosen, since the noise power bandwidth is normally wider due to the shape of the response curve. To check this, switch to the 70 c/s filter position. Using a noise input signal, set up the spectrum analyser for a suitable output. Change filter switch to 1 Kc/s and note the increase in output on monitor oscilloscope. Adjust attenuators until output returns to the same level as for 70 Kc/s condition. The ratio of the two outputs may now be calculated from the two attenuator readings. The difference should be approximately equal to 11.5 dbs ±1.5 dbs.

(c) 10 db Pad

The insertion loss of the 70 c/s filter is 10 dbs. To compensate for this, when switched to 1 Kc/s bandwidth, there is a 10 db pad which is switched in when the selector switch is set to 1 Kc/s. This can be checked by injecting a signal of suitable frequency.

Using 70 c/s filter, tune for maximum output. Note this output and switch to 1 Kc/s filter. The output should remain approximately constant.

A cross-check is also provided by test 6.5 (b) above.

7.0 SUMMARY OF PERFORMANCE

7.1 Frequency Range

The equipment measures the power level in a selected bandwidth centred at a variable frequency in the range 1-90 Kc/s.

7.2 Bandwidth

Two alternative bandwidths are available, namely 70 c/s and 1 Kc/s. Both bands may be used for accurate noise power measurements by a thermocouple milliameter or, alternatively, for the panoramic display.

7.3 Presentation

(a) Automatic

An oscilloscope which forms part of the equipment is used in conjunction with the spectrum analyser circuits to produce a trace of the signal spectrum. Two sweep ranges are provided, namely 1-7 Kc/s or 1-90 Kc/s.

(b) Manual

Accurate power measurements are made by using a manually tracked heterodyne oscillator calibrated in terms of the video signal frequency. Calibrated attenuators are employed to adjust the output power to a constant reading on a thermocouple milliameter. The attenuators read signal power level with reference to a 40 microvolt calibrating signal at 10 Kc/s.

An auxiliary function of the display tube is to monitor the output signal from the selective amplifier in manual operation.

(c) Frequency Marker

A marker system gives ease of alignment of the manual frequency control with any section of the oscilloscope display, and permits rapid calibration of it.

7.4 Sensitivity and Accuracy

Input signal components in the range from 0.1 volt to 1 microvolt r.m.s. in a 70 c/s band (a range of 100 db) can be measured with an accuracy of ± 2 db at frequencies from 500 c/s to 90 Kc/s. Measurements down to 200 c/s and up to 95 Kc/s can be made by correcting for reduced amplifier sensitivity.

The inherent noise level of the equipment corresponds to approximately 0.20 microvolt in a 70 c/s band referred to the input terminals at 5 kilohm input impedance.

7.5 Oscilloscope

The display unit incorporates a 4 in. C.R.T. with the usual adjustable controls. The front panel is provided with a viewing hood and camera mount. Both X and Y plates are driven symmetrically by simple paraphase amplifiers. The "time base" voltage is derived from the generator controlling the sweep oscillator, or alternatively, from a built-in, free-running, sawtooth generator, which is a useful aid in distinguishing random noise from periodic signal components.

8.0 OPTIONAL ALTERNATIVES AVAILABLE

Depending on the nature of the work for which it is required, certain relaxations in the specification for the Spectrum Analyser may be permissible. It may also be convenient to adopt a bandwidth or resolution which differs from that of the standard instrument. A list of the main alternatives is given below, but equipments can be manufactured to customer's prepared specification.

Ref. 190/a **Standard Equipment—70 c/s**
Filter Noise Bandwidth 70 c/s
Filter cut-off rate ... ... 75 c/s for – 35 db
Alternative available bandwidth .. 1 Kc/s

Ref. 190/b **Standard Equipment—80 c/s**
Filter Noise Bandwidth 80 c/s
Filter cut-off rate ... ... 100 c/s for – 35 db
(Slight degrading of filter response leads to saving in cost)
Alternative available bandwidth .. 1 Kc/s

Ref. 190/c **Standard Equipment—1 Kc/s**
Selective Amplifier bandwidth (no crystal filter) ... 1 Kc/s

Ref. 190/a/1 **Standard Equipment** — supplied for rack mounting without cabinet and with dust covers fitted to individual chassis.

Ref. 190/a/2 **Standard Equipment** — supplied for rack mounting without cabinet and with uncased chassis frames.

9.0 SUGGESTED APPLICATIONS

9.1

As a result of the wide frequency range, narrow resolution and high sensitivity provided, Spectrum Analyser Type 190 is an instrument of great versatility. It can be used for three principal types of measurement, with many possible subsidiary roles.

9.2 The Three Main Functions

(a) Wave Analyser

When used as a wave analyser for harmonic analysis, the number of harmonics which can be resolved will obviously depend on the fundamental frequency. Assuming the minimum

measurement range is, for practical purposes, up to the third harmonic, the instrument can be used to about 30 Kc/s as the following table shows.

Fundamental Frequency	Maximum measurable harmonic frequency
500 c/s	180th
1,000 c/s	90th
5,000 c/s	18th
30,000 c/s	3rd

The range of measurement for fundamental components is, obviously, up to 95 Kc/s.

(b) Noise Analyser

Since the analyser has a constant and accurately known bandwidth over the entire range of frequencies, it can be used for the analysis of random noise spectra, for the determination of noise factor at video frequencies, and for distinguishing between harmonic signal components and random noise co-existing in the signal spectra.

(c) As a Sideband Analyser at R.F.

The modulation spectrum on an R.F. carrier can be measured and analysed if the Spectrum Analyser is used with a suitable superheterodyne receiver and a linear type of envelope detector at the output for analysing amplitude modulations (see Fig. 12 for schematic diagram) —or with any suitable FM discriminator for FM noise analysis. This technique enables harmonic modulation components to be isolated and measured in the presence of noise of considerably greater RMS magnitude.

A fine example is given by the Allscott Noise Measuring Equipment Type 123 described in Technical Report Ref. 123/01.

9.3 Typical Measurements

(a) Fourier series of harmonic waveforms.

(b) Checking dispersion in video oscillator output.

(c) Plotting noise characteristics and video response of amplifiers employing tubes or transistors.

(d) Performance of power amplifiers, e.g., power output and harmonic distortion.

(e) Measuring amplitudes of harmonic components in presence of random noise, interference, etc., of considerably greater magnitude.

(f) Frequency response and gain characteristics of circuits such as phase sensitive detectors, etc., at very low operating levels.

(g) AM modulation sidebands spectra at RF (see Section 9.2 (c).)

(h) FM modulation sideband spectra at RF (a frequency discriminator must be used, for example see Allscott Noise Measuring Equipment Type 123, Technical Report 123/01, which employs an RF frequency discriminator).

(i) Vibration characteristic of tubes, etc., at frequencies from 500 c/s upwards.

Data in this handbook is liable to alteration without notice although every care is taken to ensure accuracy.

JAMES SCOTT & CO. (ELECTRICAL ENGINEERS) LIMITED.

SPECTRUM ANALYSER TYPE 190

COMPONENT LIST FOR 190g.

TO BE USED IN CONJUNCTION WITH TECHNICAL NOTE 190/01.

MESSRS. JAMES SCOTT & CO. (ELECTRICAL ENGINEERS) LTD.
68, BROCKVILLE STREET,
CARNTYNE INDUSTRIAL ESTATE
GLASGOW. E.2.

COMPONENT LIST RF 190g.

1.0 Component Lists for Spectrum Analyser Chassis.

REFER TO FIGURE NO. 3 TECHNICOL NOTE 190/01

1.1 Capacitors

Circuit Ref.	Value	Rating	Tol.%.
C 1	.01u	400V	±20
C 2	12u	25V	-20 +200
C3	4u8	350V	±20
C 4	.25u	250V	±20
C 5	No Component		
C 6	.005u	400V	±20
C 7	.005u	400V	±20
C 8	12u	25V	-20 +200
C 9	.001u	400V	±20
C10	4u	250V	±20
C11	.003u	400V	±20
C12	.1u	250V	±20
C13	.1u	250V	±20
C14	.1u	250V	±20
C15	.1u	250V	±20
C16	8-115P		
C17	270P	350V	± 2
C18	47P		
C19	1000P	350V	-20 +80
C20	.1u	250V	±20
C21	8-115P		
C22	270P	350V	± 2
C23	8-115P		
C24	1000P	350V	-20 +80
C25	.1u	250V	±20
C26	No Component		
C27	.1u	250V	±20

1.1 Capacitors continued

Circuit Ref.	Value	Rating	Tol.%.
C28	270P	350V	± 2
C29	330P	500V	±10
C30	.1u	150V	±20
C31	680P	500V	±10
C32	No Component		
C33	0.01u 8	400V	±20
C34	.0025u		± 2
C35	0.01u	400V	±20
C36	.01u	400V	±20
C37	.01u	150V	±20
C38	.01u	400V	±20
C39	0.25u	250V	±25
C40	.01u	400V	±20
C41	500P		
C42	8-115P		
C43	390P	350V	± 2
C44	8-115P		
C45	150P	350V	± 2
C46	8-115P		
C47	.01u	400V	±20
C48	.01u	150V	±20
C49	.1u	250V	±20
C50	.1u	150V	±20
C51	.01u	400V	±20
C52	1000P	350V	-20 +80
C53	20P	750V	± 5
C54	1000P	350V	-20 +80
C55	.1u	250V	±20
C56	.01u	150V	±20
C57	.5u	250V	±20
C58	.02u	150V	±20
C59	No Component		

1.1. Capacitors continued.

Circuit Ref.	Value	Rating	Tol.%
C.60	.5u	250V	±20
C.61	1u	250V	±20
C.62	1u	250V	±20
C.63	.1u	250V	±20
C.64	.1u	250V	±20
C.65	68P	350V	± 1
C.66	68P	350V	± 1
C.67	.1u	250V	±20
C.68	No Component		
C.69	.25u	150V	±20
C.70	.25u	150V	±20

1.2 Resistors

R. 1	270K	½W	± 1
R. 2	58K	½W	± 1
R. 3	52.2K	½W	± 1
R. 4	5.8K	½W	± 1
R. 5	No Component		
R. 6	1K	½W	±10
R. 7	4.7K	½W	±10
R. 8	47K	½W	±10
R. 9	390K	½W	±10
R.10	10.87K	½W	± 1
R.11	9.7K	½W	± 1
R.12	3.86K	½W	± 1
R.13	31.62K	½W	± 1
R.14	470K	½W	±10
R.15	1K	½W	±10
R.16	4.788K	½W	± 1
R.17	22.4	½W	± 1

1.2 Resistors

Circuit Ref.	Value	Rating	Tol.%.
R.18	470K	½W	±10
R.19	4.7K	½W	±10
R.20	33K	½W	±10
R.21	No Component		
R.22	270	½W	±10
R.23	68K	½W	±10
R.24	27K	½W	±10
R.25	8.2K	½W	±10
R.26	680	½W	±10
R.27	3.3K	½W	±10
R.28	8.2K	½W	±10
R.29	3.3K	½W	± 1
R.30	13K	½W	± 1
R.31	3.3K	½W	± 1
R.32	10K	½W	±10
R.33	470	½W	±10
R.34	3.3K	½W	±10
R.35	22K	½W	±10
R.36	470	½W	±10
R.37	3.3K	½W	±10
R.38	47K	½W	±10
R.39	3.3K	½W	±10
R.40	270	½W	±10
R.41	470	½W	±10
R.42	15K	1W	±10
R.43	47K	½W	±10
R.44	1K	½W	±10
R.45	4.7K	½W	±10
R.46	47K	½W	±10
R.47	330K	½W	±10

1.2 Resistors continued

Circuit Ref.	Value	Rating	Tol.%.
R48	820	½W	±10
R49	100	¼W	±10
R50	56K	¼W	±10
R51	No Component		
R52	No Component		
R53	No Component		
R54	49.5K	½W	± 1
R55	1K	¼W	± 1
R56	99Ω	½W	± 1
R57	10	¼W	± 1
R58	82K	1W	±10
R59	150K	¼W	±10
R60	47K	¼W	±10
R61	180	¼W	±10
R62	820	¼W	±10
R63	470	¼W	±10
R64	10K	¼W	±10
R65	3.3K	1W	±10
R66	4.7K	¼W	±10
R67	4.7K	¼W	±10
R68	1M	¼W	±10
R69	1K	¼W	±10
R70	4.7K	¼W	±10
R71	220	¼W	±10
R72	10K	¼W	±10
R73	1M	¼W	±10
R74	27K	¼W	±10
R75	100K	¼W	±10
R76	47K	¼W	±10
R77	4.7M	¼W	±10
R78	1.5M	¼W	±10

1.2 Resistors Continued

Circuit Ref.	Value	Rating	Tol.%.
R79	330K	¼W	±10
R80	1M	¼W	±10
R81	100	¼W	±10
R82	43K	½W	± 2
R83	33K	½W	± 2
R84	43K	½ W	± 2
R85	1K	¼W	±10
R86	240K	½W	± 1
R87	18K	½W	± 2
R88	47	¼W	±10
R89	330K	½W	± 2
R90	100K	½W	± 2
R91	430K	½W	± 2
R92	75K	½W	± 2
R93	8.2K	½W	±10
R94	6.8K	1W	±10
R95	18K	1W	±10
R96	1M	¼W	±10
R97	100	¼W	±10
R98	100	¼W	±10
R99	33K	1W	±10
R100	22K	1W	±10
R101	22K	1W	±10
R102	33K	1W	±10
R103	100	¼W	±10
R104	100	¼W	±10
R105	18K	10W	±10
R106	8.63K	¼W	±1
R107	7.7K	¼W	±1
R108	6.87K	¼W	±1
R109	6.11K	¼W	±1
R110	5.45K	¼W	±1

1.2 Resistors Continued.

Circuit Ref.		Value	Rating	Tol.%
R111		4.86K	¼W	± 1
R112		4.33K	¼W	± 1
R113		1.512K	¼W	± 1
R114		478.8	¼W	± 1
R115		152.2	¼W	± 1
R116		47.6	¼W	± 1
R117		1K	¼W	± 10
R118		100	¼W	± 10
R119		62K	¼W	± 10
R120		47	¼W	± 10
R121		1.5K	¼W	± 10
R122		120	¼W	± 10
R123	Supplied with L.P.1.	220K	¼W	± 10
R124	No Component			
R125	No Component			
R126	No Component			
R127	No Component			
R128	No Component			
R129	No Component			
R130	No Component			
R131		10M	¼W	± 10
R132		10M	¼W	± 10

1.3 Variable Resistors.

RV1		50K	¼W	± 20
RV2		100	1W	± 20
RV3		1K	¼W	± 20
RV4	No Component			
RV5		1M	¼W	± 20
RV6		5K	¼W	± 20
RV7		100	1W	± 20
RV8		250K	¼W	± 20
RV9		50K	¾W	± 20
RV10		25K	¼W	± 20
RV11		100K	¼W	± 20
RV12		20K	¼W	± 20
RV13		2.5K	1W	± 20
RV14		25K	¼W	± 20

1.4 Tubes.

V1	Mullard	EF86 (American Equiv. - 6267)
V2	Mullard	EF86 (American Equiv. - 6267)
V3	Mullard	EF86 (American Equiv. - 6267)
V4	Mullard	EF91 (American Equiv. - 6AM6
V5	Mullard	0A71
V6	Mullard	0A71
V7	Mullard	0A71
V8	Mullard	0A71
V9	Mullard	EF91 (American Equiv. - 6AM6)
V10	Mullard	EF91 (American Equiv. - 6AM6)
V11	Mullard	EF91 (American Equiv. - 6AM6)
V12	Mullard	0A71
V13	Mullard	EF91 (American Equiv. - 6AM6)
V14	No Component	
V15	Mullard	EF91 (American Equiv. - 6AM6)
V16	Mullard	EF91 (American Equiv. - 6AM6)
V17	Mullard	0A71
V18	Mullard	0A71
V19	Mullard	0A71
V20	Mullard	0A71
V21	Mullard	12AT7 (American Equiv. - 12AT7)
V22	Mullard	6F33
V23	Mullard	EA76 (American Equiv. - 6489)
V24	Mullard	EA76 (American Equiv. - 6489)
V25	Mullard	12AT7 (American Equiv. - 12AT7)
V26	Mullard	EF91 (American Equiv. - 6AM6)
V27	Mullard	12AT7 (American Equiv. - 12AT7)
V28	Mullard	EF91 (American Equiv. - 6AM6)

1.5 Switches.

SW1	Drawing No. B31 (2 Pole - 6 way Wafer Switch with S.P.D.T. Switch)
SW2	Drawing No. B30 (1 Pole - 11 way Wafer Switch)
SW3	Drawing No. B32 (1 Pole- 6 way Wafer Switch)
SW4	Drawing No. B28 (2 Pole - 2 way Wafer Switch)
SW5	No Component
SW6	Drawing No. B29 (6 Pole - 4 way Wafer Switch with S.P.D.T. Switch)
SW7	N.S.F. Type 8373/B4 (3 Amp - Double Pole, Double Throw.)
SW8	N.S.F. Type 8373/B4 (3 Amp - Double Pole, Double Throw).
SW9	N.S.F. Type 8280/B3 (3 Amp - Single Pole, Single Throw).

1.6 Transformers

Circuit Ref.

TR1	Drawing No. A518		
	PRIMARY:	(1)	1000 Ohms
		(2)	1000 Ohms
	SECONDARY:		8000 Ohms
TR2	Drawing No. A519		
	PRIMARY:		10,000 Ohms
	SECONDARY:	(1)	1000 Ohms
		(2)	1000 Ohms
TR3	Drawing No. A586		
	PRIMARY:		5000 Ohms
	SECONDARY:	(1)	1000 Ohms
		(2)	1000 Ohms
TR4	Drawing No. A518		
	PRIMARY:	(1)	1000 Ohms
		(2)	1000 Ohms
	SECONDARY:		8000 Ohms.

1.7 Inductances

		Value
L1	No component	
L2	Drawing No. A150	2.5 mH
L3	Drawing No. A150	2.5 mH
L4	Drawing No. A151	2.5 mH
L5	Drawing No. A120	100 mH
L6	Drawing No. A116	1.7 mH

1.8 Sockets

SK1	Amphenol Ref. No. UG1094/U
SK2	Mullard Type WWC.57 (To suit P.O. Filter W.92)
SK3	Mullard Type WWC.57 (To suit P.O. Filter W.92)
SK4/1/2/3	Belling Lee Type L653/5
SK5	No Component.
SK6	No Component
SK7	No Component
SK8	No Component

1.9 Plugs

Circuit Ref.

PL1	Amphenol	Ref.UG910/U
PL2	Amphenol	Ref.UG910/U
PL3	Amphenol	Ref.UG910/U
PL4	Attached to Filter	
PL5	Attached to Filter	
PL6	Plessey	Ref.CZ 49458 (12-pin, 5 amp.)
PL36	Amphenol	Ref.UG1094/U
PL37	Amphenol	Ref.UG1094/U

1.10 Lamps

LP1 Arco-Electric Switches Ltd.
Cat. No. SL/90/N (with red lens).

1.11 Fuse

FS1 Belling-Lee 250 mA, Type L.1055, Size 0.

1.12 Crystal

XL1 Drawing No.A582 - Salford Electrical Ltd.
Fre uency: 150 Kc/s
Frequency Tolerance: $\pm$0.01% in a range -10^{o}C to $+80^{o}$C.

1.13 Filter

XF1 Aveley Electric Ltd.
Crystal Lattice Filter, Type XF.81838;
150 Kc/s; $\pm$37 c/s.

1.14 Meter

M1 and X1 Drawing Ref. A439.
Thermocouple Milliammeter, scaled in standard divisions; 0 - 2.5 mA.

1.15 Subsidiary List of Mechanical Items which may require replacment.

Switch and potentiometer knobs - E.K. Cole Ltd; Type WT.40119.

Fuseholder - Belling-Lee; Type L.356, size O.

Indexing Plate - Drawing No. B53.

Slow-motion dial - Muirhead & Co.Ltd.; Type D-111-C.

BEST V.T.
R 2-5 MA
H. RES 400 Ω
COUPLE Ω 8 Ω
OUTPUT 7 M.V

FELIXSTOWE
ENGLAND.